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EFFECTS OF THE FINNISH SAUNA BATH ON THE ELECTROLYTE EXCRETIONS AND THE RENAL CLEARANCES

BY

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E. H.

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INFLUENCE OF HEAT ON THE FLUID BALANCE

Several disturbances in the fluid balance of the human organism which are produced by heat have been known for already some time. A disturbance of this kind is, among others, heat cramp, which is a result of salt deficiency (e.g., Talbot 1935). The condition leading to it is a lengthy exposure to intense heat during which water with no salt added is drunk to compensate the excessive loss of fluid in sweat. On the other hand, we have very little knowledge of the effects of a short exposure to intense heat, as in the Finnish sauna bath, on the fluid balance, of the possible occurrence of mechanisms compensating the fluid and salt losses, and of the significance of such mechanisms.

CHARACTERISATION OF AMBIENT HEAT IN PHYSIOLOGICAL STUDIES

It is a well known fact that the effect of heat on the organism depends on a number of factors in addition to the environmental temperature. Such factors are humidity, radiant heat, movement of the air, clothing, etc. In order to make the comparison of different heat conditions possible, attempts have been made to develop scales indicating the environmental heat, in which the above mentioned contributing factors have been taken into consideration to varying extents. The first index devised for this purpose was the »effective temperature scale» developed by Houghten and Yaglo-glou (1923), which is compiled from readings of the dry and wet bulb temperatures and the speed of movement of the air. The results of studies carried out by Robinson, Turrel and Gerking (1945) in an air-conditioned room at temperatures of 23°—50°C

seem to indicate, however, that in hot environments the effective temperature over-emphasises the importance of the dry bulb temperature in relation to the wet bulb temperature. Yaglou (1949) admitted that the effective temperature scale makes too much allowance for humidity at low temperatures and not enough allowance at high temperatures. The error is greatest under very hot conditions which approach the limit of man's endurance to heat. The scale was improved to make allowance for radiant heat by Bedford (1946), who used the term »corrected effective temperature» for the temperature thus obtained.

McArdle *et al.* (1947) claimed that the rate of sweating can be considered a good index of the effect of heat. On the basis of their experimental results they devised a nomogram which makes it possible to predict the amount of sweat that would be perspired during a period of four hours in various hot environments. In addition to the factors mentioned above, clothing and muscular work are taken into consideration in making the estimate. Wyndham *et al.* (1953) found that the body temperature, pulse rate and observed sweat rate are directly proportional to the sweat rate estimated by means of the nomogram. However, Smith (1955) demonstrated that the error possible in predicting individual sweat rates may be large. Blockley *et al.* (1954) in their studies on human tolerance limits at high temperatures used a »heat storage index» calculated on the basis of the mean body temperature.

Sauna Environment. — In a Finnish sauna bath the human body is exposed to the effects of dry, hot air. Temperatures in different sauna bath-houses may vary to a certain extent, since each bath-house has its own peculiar qualities determined by the type of construction, building material, method of heating, and other factors. Furthermore, each sauna bather modifies the bathing conditions according to his individual habits. The effect of the heat can be intensified as desired by throwing a little water on the hot stones on top of the furnace. The relative humidity of the air, which originally was dry, then increases for a short time and the air is brought into circulation. The effects of heat can also be increased by beating the skin with a soft whisk of leafy birch branches, which also moves the hot air. The heat and humidity of the air differ essentially at different levels within the sauna room, for example on the floor and on the raised platform. Dry bulb

readings in the Finnish sauna at the platform level range from 50° to over 100°C, wet bulb readings from 30° to 50°C, relative humidity from 5 to 40 per cent, and the bathing time from 10 to 35 minutes (Lundgren 1933, Brofeldt 1942, Ott 1948, Viherjuuri 1954, Eisalo 1956, Lehtmets 1957). The traditional sauna bath is followed by a rapid cooling of the body with cold water. The effects of a sauna bath cannot be compared with the effects of other hot environments with the aid of the above mentioned heat stress indices, since these scales do not extend to the high temperatures usually prevailing in a Finnish sauna bath.

THERMAL SWEATING

The water evaporating from the skin of a resting man at room temperature is chiefly water vapour diffusing through the skin. It has been found (Burch and Winsor 1944 a and b) that the fluid loss per unit of skin area at room temperature is virtually the same for living and dead human skin. Healthy persons at complete rest and patients with atrophy of the sudoriferous glands show a corresponding fluid loss. The evaporative loss in all of these cases consists of insensible perspiration alone, which only follows physical laws and is independent of the vital functions. Burch and Winsor (1944 b) also demonstrated that the rate of diffusion is directly related to the skin temperature. Pinson (1942) studied insensible perspiration from human skin with inactivated sweat glands and found it to be doubled when the skin temperature increased by 10°C. Sweating may also take place in a resting subject at room temperature and it is then due in most cases to emotional causes. Emotional perspiration is generally restricted to the skin of the palms, soles and axillae. Psychic factors may cause general body sweating only when the environment is warm or the factors particularly strong (Kuno 1956). According to Kuno, an increased environmental temperature alone causes sweating in all areas of the skin with the exception of the palm and the sole. All references to sweat and its components in the present investigation refer to thermal sweating.

Initiation of Sweating. — Determination of the time when sweating begins depends upon the method used, since an increase in the rate of evaporation is observed before the appearance of

sweat drops. Gagge (1940) observed that the rate of evaporation from the skin of a resting person increases only slightly with rising temperatures up to 31°C but sharply thereafter. Burch (1948) found that a resting man begins to sweat when the dry temperature rises to 34.4°C with a relative humidity of 50 per cent, or to 39°C in very dry air (relative humidity 9 per cent). According to Grayson (1949), also, sweating is initiated at about 40°C in dry air. Bazett (1951) reported that the resting man begins to sweat only after his mean skin temperature has risen to 34.5°C. According to Hertzman *et al.* (1952), regional sweating in different skin areas begins at different environmental temperatures. On the other hand, Kuno (1956) found a simultaneous onset of sweating in all regions of thermal sweating, although marked differences were seen in the regional sweating rates owing to variations in the skin temperature and to other factors. Pinson (1942) demonstrated that sweating is not visually observable until 10 minutes after transition to a hot environment. At this time the increase of evaporation is still as slight as 0.02 mg. per sq.cm. of skin area per minute. Adolph (1946) reported that in hot air having a temperature of 50°C and a relative humidity of 10 per cent the evaporated amount begins to increase owing to sweating in 7—12 minutes and rises in about 20 minutes to the maximum, or to about 10 times the amount of evaporation at a cool temperature. Thermal sweating is thus generally initiated only after a latent period and the sweating rate increases gradually. This is probably due to the gradually increased irritability of the sweating centre in the brain (Kuno 1956). The more abrupt the increase in temperature, the shorter the latent period; the latter may occasionally be absent. Hertzman *et al.* (1953) observed that in the cases studied by them the transition from ordinary room temperature to a hot environment (40°—45°C) was followed by an immediate onset of sweat discharges on all skin areas under observation.

Initiation of Sweating in the Sauna. — Man begins to perspire visibly in the Finnish sauna in 8—12 minutes (Lundgren 1933, Ott 1948). In Lundgren's studies the body weight, determined in a balance scale, increased slightly immediately after the person entered the sauna. This was presumably due to the condensation of water vapour on the skin. During the first 10 minutes in the sauna a higher weight was registered than immediately before, and

at its highest it was 20—30 gm. greater. It began to decline thereafter with the onset of perspiration.

Amount of Sweat. — The sweat excreted on the skin either evaporates, remains on the skin, or flows off. Kuno (1956) observed that during heavy perspiration the amount of sweat remaining on the total cutaneous surface is 30—50 gm. Greater variation is seen in the amounts evaporating and flowing off. The amount of evaporation depends upon the moisture of the air. The total amount of sweat also differs in dry heat and humid heat. Lee *et al.* (1941) and Ladell (1945 b) reported that when the same amount of work was performed in a dry hot and a humid hot climate the sweat output was greater in the first mentioned. Molnar *et al.* (1946) found that the consumption of fluids and amount of sweat under the dry, hot desert conditions of California were twice as high as in the tropical humid heat of Florida. According to their study the evaporated amounts were correlated to the radiation of the sun and the dry bulb readings. Eichna *et al.* (1945) found that a moderate deficiency of water had no effect on the amount of sweat. The latter is also not greatly influenced by the drinking of a volume of water equal to the fluid loss (Pitts, Johnson and Consolazio 1944) or greater (Ladell 1945 b). Ladell carried out experiments in a dry desert climate and observed that the amount sweated by persons drinking 1 per cent saline solution is slightly smaller than that of persons ingesting an equal volume of water. The sweat rate varies in different skin regions and marked individual differences are observable (Burch and Sodeman 1943, Hertzman 1954 and Kuno 1956). According to studies by Weiner (1945), Hertzman and Kuno, the rate generally is greater on the forehead, neck and trunk than on the extremities. On the back and chest it is higher than on the lateral zones of the trunk (axillae included), and on the lateral aspect of the thigh higher than on its anterior aspect. Kuno also observed that when the subject is lying on his side the sweating is greater on the uppermost than on the lower side of the body. The pressure to which the extremity and the lateral aspect of the trunk are subjected has a reflectory effect, thus decreasing the sweating of the ipsilateral extremity and increasing that of the contralateral extremity.

Amount of Sweat in the Sauna. — In earlier investigations the sweat loss induced by the Finnish sauna bath has been determined

TABLE 1

EARLIER INVESTIGATIONS ON THE AMOUNT OF SWEAT IN THE FINNISH SAUNA

Author(s)	Test Persons		Amount of Sweat, gm.	
	Number	Sex	Mean	Range
Lundgren (1933)	1010	♂	458	100—1150
von Knorre (1943)	..	♂	500	250— 750
Bartels (1944)	..	♂	..	200—1000
Ott (1948)	16*	♀	233	50— 600
	121*	♂	303	50—1000
Räsänen (1951)	7	♀	600	200— 950
Hasan, Laamanen and Niemi (1954)	19	♂	450	..
Fritsche (1956)	..	..	500	200—1000
Eisalo (1956)	25	♂	900	200—2100

* Number of baths

as a weight loss. The results obtained in these studies are shown in table 1. Lundgren observed the most rapid loss at the end of the sauna bath and during about 10 minutes thereafter. In his studies the loss of weight was greater in a dry than in a humid sauna, averaging 540 gm. in the former and 420 gm. in the latter. Karvonen, Friberg and Anttila (1955) found that under sauna conditions the drinking of water had no effect on the amount of sweat. Gernandt *et al.* (1944) calculated that in a Finnish sauna having a temperature of 80°C, relative humidity of 10 per cent, and air movement of 0.5 m./sec. the maximum evaporation into the air from the total cutaneous surface may be 220 gm. in 10 minutes. If the sweating is more profuse the excess amount will remain on the skin or flow off.

Body Temperature in the Sauna. — In the sauna, heat is transferred to the body chiefly by radiation, convection and conduction. Although a considerable evaporation of sweat into the air in the sauna takes place, causing a marked loss of body heat, it is not adequate to retain the body temperature at a normal level. Already in 1765 Martin observed that the body temperature rises in the sauna. The rectal temperature was found by von Knorre (1943) to rise by 0.8°—2.3°C to 37.8°—39.2°C. According to him the hyperthermia lasts for about 1 hour if the sauna bath is followed by a cold shower. Bardenheuer (1943) reported body temperatures of 38°—39°C but did not specify how they were measured. Bartels

(1944) observed after the sauna bath axillary temperatures of 37°—38°C, which reverted to normal in 3 hours. The sublingual temperature measured immediately after the sauna was, according to Ott (1948), 39.7°C at the maximum and averaged 38.2°C. It returned to normal in 4—5 minutes after a cold bath and in 1—1½ hour without it. Lower body temperatures were not seen during regularly repeated sauna baths. Hasan, Laamanen and Niemi (1954) reported that the rectal temperature rose, on an average, to 38.3°C and the skin temperature to 38.9°C. Luder (1954) found that the »body temperature» rises in the sauna by 1.35°—1.6°C and the skin temperature to 38.0°C, and that these revert to normal immediately after a shower or at least within 1 hour. Eisalo (1956) mentioned rectal temperatures in the sauna of 37.7°—39.2°C, averaging 38.2°C. The heat conditions differed greatly in the studies referred to above.

SODIUM, CHLORIDE AND POTASSIUM CONCENTRATIONS OF SWEAT

Sweat is hypotonic in relation to plasma. There are, however, marked variations in the electrolyte concentrations of sweat. Although many factors which produce these variations have been stated in the literature, opinions on the significance of such factors are conflicting.

Individual Differences in the Salt Concentration of Sweat. — Several investigators state that there are great individual variations in the salt concentration of sweat (Whitehouse 1931 and 1935, Dill *et al.* 1933, Dill, Hall and Edwards 1938). The sodium chloride concentrations reported in the literature are highly variable, with individual values of 5 mEq./l. or even lower and some others as high as 100 or 148 mEq./l. The potassium concentration has been observed to vary in the range 1—15 mEq./l. (Robinson and Robinson 1954).

Influence of Sweat Collection Technique on the Chloride Concentration. — Owing to the ease of the chemical analysis, the chloride concentration of sweat has received the most study. Kittsteiner (1911) and Mickelsen and Keys (1943) observed that the chloride content of sweat varies according to the skin area. The method of sweat collection therefore also influences the result.

Sweat accumulating into an impermeable bag completely enclosing an upper extremity is more concentrated than that excreted freely from the whole body surface (Mickelsen and Keys 1943, Robinson, Kincaid and Rhamy 1950 b, van Heyningen and Weiner 1952). However, Ladell (1945 b and 1948) is of the opinion that the skin area of the upper extremity is sufficiently large and representative to make an estimation of the total salt loss possible. On the other hand, Weiner and van Heyningen (1952 a) and Hertzman (1954) concluded that this technique does not provide a sufficiently dependable basis for such an estimation.

Some Correlations of the Chloride Concentration of Sweat. — When a number of successive sweat samples are taken during the same exposure to ambient heat, a higher chloride concentration is seen in the later samples (Hancock, Whitehouse and Haldane 1929, Ladell 1945 a). According to most authors, the chloride content rises with an increase in the sweating rate, in other words, the greater the quantity of sweat excreted, the less chloride ion can be retained by the sweat glands (Kittsteiner 1911 and 1913, Dill, Hall and Edwards 1938, Böttner and Schlegel 1940, Locke *et al.* 1951). Ladell (1945 a) did not agree with this opinion. The concentration of chloride in sweat increases as the temperature of the skin rises (Kittsteiner 1913, Lehman and Szakáll 1939, Johnson, Pitts and Consolazio 1944, Ladell 1945 b, Robinson *et al.* 1950, Weiner and van Heyningen 1952 b). According to most investigators there is no correlation between the rectal or sublingual temperature and the chloride content of sweat (Hancock, Whitehouse and Haldane 1929, Taylor *et al.* 1943, Johnson, Pitts and Consolazio 1944, Ladell 1945 a). On the other hand, Lehman and Szakáll (1939) and Henn (1953) observed a positive correlation between the chloride concentration of sweat and the »body temperature».

Effect of Ingestion of Water and Salt on the Chloride Concentration. — Opinions differ concerning the effect of the ingestion of water and salt on the concentration of chloride in sweat. Most authors report that the salt content of sweat is low in persons on a low-salt diet and high when a large amount of salt is given (Kittsteiner 1911, Hancock, Whitehouse and Haldane 1929, McCance 1938, Ladell, Waterlow and Hudson 1944, Conn 1949 a, Locke *et al.* 1951). On the contrary, Cuthbertson and Guthrie (1934) found that the salt content of sweat was unaffected by the amount

of salt in food. According to most investigators, the salt concentration of sweat declines when a large amount of water is ingested (Hancock, Whitehouse and Haldane 1929, Johnson, Pitts and Consolazio 1944).

Acclimatisation to Heat and Its Effect on the Sweat Chloride. — The human body becomes gradually acclimatised to ambient heat, usually in 5—14 days. This takes place if the subject remains in a hot environment continuously or at least several hours daily. Acclimatisation to heat is effectively promoted by muscular work (Bass, Kleeman and Quinn 1953). The improved heat tolerance is manifested especially during physical stress under these conditions. The increases in the pulse rate and rectal temperature are less marked, the rate of sweating is greater, and the efficiency and subjective well-being are higher than those of a person unacclimatised to a hot climate (Adolph 1947, Conn 1945 a, Robinson, Kincaid and Rhamy 1950 a). Acclimatisation to heat also causes a decrease in the chloride concentration of sweat, according to most authors (Dill *et al.* 1933, Talbot *et al.* 1933, Daly and Dill 1937, Dill, Hall and Edwards 1938, Lehman and Szakáll 1939, Mickelsen and Keys 1943, Johnson, Pitts and Consolazio 1944, Conn 1949 a, Weiner and van Heyningen 1952 a), but Ladell (1945 a) claimed that it has no effect on the sweat chloride. McCance (1938), Robinson, Kincaid and Rhamy (1950 b) and Weiner and van Heyningen (1952 a) found that a decrease in the chloride concentration is associated with acclimatisation only in the case of a negative chloride balance due to a marked salt loss.

Sodium and Potassium Concentrations of Sweat. — The sodium concentration of sweat is closely correlated to the chloride concentration (Dill *et al.* 1933, Daly and Dill 1937, Dill, Hall and Edwards 1938, Robinson *et al.* 1950, Locke *et al.* 1951, Ahlman *et al.* 1953 b). The sodium and chloride concentrations generally are lower in sweat than in plasma, but occasionally are nearly as high. The potassium content of sweat, however, is usually as high as or higher than that of plasma. The sweat potassium is highest at the onset of sweating and gradually declines as sweating continues (Fukuda 1947, Kawahata 1951, Berenson and Burch 1953, Ahlman *et al.* 1953 a).

Sodium, Chloride and Potassium Concentrations of Sweat in the Sauna. — It was estimated by von Knorre (1943) that 1—2 gm.

TABLE 2

EARLIER INVESTIGATIONS ON THE SODIUM, CHLORIDE AND POTASSIUM CONCENTRATIONS OF SWEAT IN THE FINNISH SAUNA

Authors	Test Subjects		Mean Concentration in Sweat, mEq./l.		
	Number	Sex	Sodium	Chloride	Potassium
Ahlman, Eränkö, Karvonen and Leppänen (1952)	4	♂	56.0	38.7	10.5
Ahlman, Eränkö, Karvonen and Leppänen (1953 b) ..	67	♂	58.42	45.39	10.00
	69	♀	63.60	43.68	12.22
Hasan, Laamanen and Niemi (1954)	19	♂	69.2	59.9	7.84
Miettinen and Anttila (1955)	19	♂+ ♀	62.9	..	9.94
Karvonen, Friberg and Anttila (1955)	7	♂	61.0	54.8	12.2

of sodium chloride is lost during a sauna bath, but he performed no investigations on this point. Table 2 lists the earlier studies on the sodium, chloride and potassium contents of sweat in the sauna. The sweat was collected in all cases into a plastic bag placed around an upper extremity. Karvonen, Friberg and Anttila (1955) observed that the sodium, chloride and potassium concentrations of sweat excreted in the sauna were unaffected by the ingestion of water. Ahlman *et al.* (1953 a) reported that when the duration of the sauna bath is prolonged the sodium and chloride contents of sweat remain unchanged but the potassium content decreases significantly. Miettinen and Anttila (1955) found that when the sauna bath is repeated after 3 hours a significant decrease in the sweat sodium and the sodium/potassium ratio may be seen in connection with the second bath, whereas the potassium content remains unchanged. On the other hand, when the bath is repeated 1—3 days later, a significant increase is seen in the sodium and chloride concentrations of sweat but there is no essential change in the potassium concentration (Ahlman *et al.* 1953 a). It was also observed by Ahlman *et al.* (1952) that during severe physical stress lasting 4 days the sweat sodium and chloride declined but the potassium remained unaltered.

INFLUENCE OF HEAT ON THE RENAL EXCRETION OF WATER, SODIUM, CHLORIDE AND POTASSIUM

The excretion of sweat necessary for the elimination of heat results in a change in the fluid and electrolyte balances of the body. Since renal function is one of the most important factors which influence these balances, the effect of exposure to heat on renal function is also a subject of interest.

Diuresis in a Hot Environment. — It has been known for a long time that diuresis is diminished in a hot environment. Already in 1765 Martin found that the Finnish sauna bath reduces diuresis. A diminished diuresis during the sauna bath was observed by von Knorre (1943), and after the bath by Bardenheuer (1943). Both reported that the specific weight of urine increases at the same time. Ott (1948) also found an increased specific weight in most cases. Hellman and Weiner (1953) and Itoh (1954) demonstrated that the diminished diuresis in a hot environment is due to an increased secretion of the antidiuretic hormone. Karvonen, Friberg and Anttila (1955) also stated that exposure to heat in the sauna bath caused an antidiuretic response and they suggested the increased secretion of antidiuretic hormone as the probable cause. Fritsche (1956), on the other hand, claimed that the sauna bath causes increased diuresis but he presented no experimental results.

Effect of Heat on Salt Excretion in Urine. — Gruzdev (1889) observed that a steam bath decreases the chloride concentration of urine. Dill *et al.* (1933) and Talbot *et al.* (1933) studied how transition from a lower temperature to hot and dry desert conditions influenced the excretion of fluid and salt. They observed that during the first few days the excretion rate of sodium and chloride in the urine declined markedly. At this time the salt content of sweat was still high. Continued exposure to heat gradually increased the excretion of salt in the urine at the same time as the salt content of the sweat decreased. Thus the reaction of the kidneys in this respect is more rapid but more transitory than that of the sweat glands. Kanter (1955) and Bass *et al.* (1955) carried out experiments in an air-conditioned room under temperature conditions resembling those of a desert. In his experiments the test subjects were exposed to a temperature of 49°—54.5°C and a relative humidity of 10—20 per cent for 4—6 hours, during which time they

drank no water. The urine volume as well as the sodium and chloride excretion rates declined, but their concentrations remained unchanged. No consistent change was seen in the urine potassium; in most cases there was an increase. Bass *et al.* had also observed a decrease in the urine volume and in the urinary sodium and chloride excretion rates. During continuous stay in a hot-air room having a day-time temperature of 49°C, a nocturnal temperature of 38°C and a relative humidity of 28 per cent, a decrease occurred in the sodium chloride excretion during the first 4 days only, and the sodium/potassium ratio was also low at this time. The effect of various humidity conditions on the salt and water excretion of the kidneys appears to be very similar. Molnar *et al.* (1946) observed that when fluid was freely available the diuresis and the salt excretion in the urine are the same under desert and tropical conditions although the ingestion of fluids and the amount of sweat are twice as large in the former as in the latter. A small rise in the temperature apparently has no effect on the sodium and chloride excretions. Thus, for example, Conley and Nickerson (1945) observed no definite change in the sodium and chloride excretion rates in the urine in a temperature as low as 30.5°C.

Mechanism of Renal Salt Excretion in Ambient Heat. — Theoretically the decrease in sodium and chloride excretions in the urine may be due either to diminished filtration or to increased reabsorption in the kidneys, or to both. According to studies by Baráth (1954), the chloride clearance is reduced in a temperature of 50°C, while the reabsorption of chloride remains unchanged. Weiner (1947) examined men working in hot air of temperature 37.8°C dry bulb and 34.5°C wet bulb and observed a fall in the urinary excretion of salt during and after exposure to heat. The changes were independent of diuresis and were demonstrable even when the water and salt losses were compensated. He believed that the decreased chloride excretion was a result of its specific retention in the kidneys.

ADRENOCORTICAL INFLUENCE ON ELECTROLYTE EXCRETIONS AT ROOM AND HIGH TEMPERATURES

The adrenocortical hormones influence considerably the sodium and potassium balances of the human organism. The hormone most

active in this respect is aldosterone, which was isolated by Simpson *et al.* (1953) and the structure of which was also clarified by the same group of investigators (Simpson *et al.* 1954). After the peroral or parenteral administration of aldosterone to man a decreased urinary excretion of sodium and chloride is seen (e.g., Mach *et al.* 1954, Prunty *et al.* 1954, Salassa *et al.* 1955, Thorn *et al.* 1955 a and b). It was observed by Mach *et al.*, Salassa *et al.* and Thorn *et al.* (1955 b) that the urinary potassium excretion slightly increased at the same time. On the other hand, Prunty *et al.* and Sheppard *et al.* (1955) found no definite change in the potassium excretion in the urine. The effect of aldosterone is very clearly seen as a lower sodium/potassium ratio in the urine (Thorn *et al.* 1955 a and b) or as an increased potassium/sodium ratio (Prunty *et al.* 1954, Luetscher and Curtis 1955 a and b). An inverse relationship has been demonstrated between the urinary excretion of aldosterone and sodium (Luetscher and Johnson 1954, Luetscher and Curtis 1955 a and b). Since the diurnal variations in aldosterone excretion vary in different individuals, this relationship is not always clearly demonstrable in urine samples collected during less than 24 hours (Luetscher and Curtis 1955 b, Venning, Dyrenfurth and Giroud 1955). It has been demonstrated in experiments with adrenalectomised rats that aldosterone causes an increased tubular reabsorption of sodium (Sala and Luetscher 1954).

Secretion of Adrenocortical Hormones in Hot Environments. — Pekkarinen and Kinnunen (1951) studied in six persons the urinary 17-ketosteroids and blood eosinophils before and during the Finnish sauna bath. They reported an increase in the mean excretion rate of the 17-ketosteroids, and a decrease in the mean eosinophil count but did not state the accuracy of the mean. Vivario *et al.* (1952), in studying the effect of a tub bath of 40°C on the blood eosinophils and urinary 17-ketosteroids, found that a hot bath has a stimulating effect on the adrenal cortex. Hellman *et al.* (1954) found that the excretion of compounds E and F and of tetrahydrocortisone were not increased during heat stress. In the experiments of Sydnor *et al.* (1955) a temperature of 49°C produced no significant change in the ACTH (adrenocorticotrophin) or corticosteroid contents of the blood. Bass *et al.* (1955) observed the typical fall in the urinary excretion rate of sodium and chloride in a hot environment. Despite this, however, there was nothing pointing to an increased secretion

of 17-ketosteroids. The 17-ketosteroids in the urine decreased and no essential change occurred in the blood eosinophil or leukocyte numbers. Although an increase in the secretion of some adrenocortical hormone at high environmental temperature had been postulated, hormone determinations failed to demonstrate this until knowledge was obtained of the mineralocorticoid named aldosterone. Collins *et al.* (1955) had eight men exposed for 2 hours daily to hot air of dry bulb temperature 36.5°C and wet bulb temperature 35.5°C and observed an increased excretion of aldosterone. The authors did not consider the change to be due to a negative salt balance but directly to the heat. Streeten *et al.* (1955), in experiments with four persons, also found a marked increase in the aldosterone excretion rate at high environmental temperatures. At the same time the urinary excretion rate of sodium and chloride decreased and the sodium/potassium ratio in the sweat declined. Falbriard *et al.* (1955) observed that the urinary aldosterone of his one test subject was markedly greater during the two days of exposure to hot air than before or after this exposure. At this time there was a decrease in the excretion of salt and water in the urine but no change in the excretion of 17-hydroxycorticoids.

Administration of Adrenocortical Hormones at High Temperatures. — When Hermanson and Hartman (1945) kept rats in hot, very humid air of a temperature of 38.7°C the normal rats survived in 93 per cent but adrenalectomised rats only in 14—17 per cent. The administration of salt raised the survival rate of the adrenalectomised rats to 27—53 per cent and the administration of DCA (desoxycorticosterone acetate) to 78—89 per cent. Adrenocortical extract gave approximately the same result, i.e., 89 per cent. Moreira *et al.* (1945) gave adrenocortical extract to two men marching in the heat. There was no change in the sodium and chloride excretion rates in the urine, whereas the potassium excretion increased. The sodium chloride concentration of sweat decreased and that of potassium increased. However, definite conclusions were not possible because of the small size of the series. Conn, Johnston and Louis (1946) made the observation that DCA decreases the excretion rate of sodium chloride both in sweat and in urine at hot temperatures. After discontinuance of the administration of DCA the sodium chloride in the sweat rises and the acclimatisation to heat is disturbed for some days. The injection of DCA or ACTH

produces a decline in the sodium chloride content of sweat (Ladell 1945 c, Conn *et al.* 1948, Conn 1949 b, Conn and Louis 1950, Robinson, Kincaid and Rhamy 1950 a, Locke *et al.* 1951). According to the observations of Conn and Louis (1950) the urinary excretion rate of sodium chloride falls during the first days of ACTH administration in a hot environment, but then regains its earlier level regardless of the continued administration of ACTH.

EFFECT OF HEAT ON RENAL CLEARANCES

Renal clearance tests make it possible to study the renal haemodynamics, as will be explained in greater detail in the next chapter. Among other methods, the creatinine and inulin clearance tests are used for determination of the glomerular filtration rate, and the diodrast and para-aminohippuric acid (PAH) clearance tests for examination of the renal blood flow.

The effect of a hot tub bath on creatinine clearance was studied by Richter (1942), who found a rise in 17 cases and a fall in 11 cases. Gukelberger (1945) observed that a 30 minutes' tub bath of a temperature of 36—37°C increased the inulin clearance by 23.3 per cent. The effect of hot environmental temperature on the inulin and diodrast clearances was studied by Byfield, Telser and Keeton (1943). The studies were carried out both in hot, dry air (37.5°C dry bulb and 20.3°C wet bulb) and in hot, humid environment (37.5°C dry bulb and 30.1°C wet bulb). The inulin clearance remained unchanged under all circumstances, and the diodrast clearance showed occasionally a slight decrease. Radigan and Robinson (1949) carried out renal clearance tests at room temperature and a high temperature (50°C dry bulb and 27°C wet bulb) on different days. The glomerular filtration rate and the renal blood flow decreased in the hot environment. Smith, Robinson and Pearcy (1952) also performed a study under the same heat conditions but were unable to find any change in the glomerular filtration rate or in the renal blood flow in the hot environment. Only in the case that the heat produced dehydration amounting to 4—8 per cent of body weight the glomerular filtration rate declined by an average of 12 per cent from the controls. According to Kenney (1952), the glomerular filtration and renal blood flow of West Africans is reduced in hot, humid environment (43.3°C dry bulb

and 35°C wet bulb). Baráth (1954) determined the endogenous creatinine and PAH clearances at ordinary room temperature and in the hot-air room having a temperature of 50°C, in which the stay lasted 30 minutes. He used only one period at each temperature. Both clearances declined in heat in all of the 10 cases studied, the former by an average of 15.2 per cent and the latter by 16.0 per cent.

STUDIES OF RENAL FUNCTION BY CLEARANCE TESTS

Renal clearance tests are among the methods used for study of kidney function. The concept of clearance was introduced by Möller, McIntosh and Van Slyke (1929). The renal clearance of a substance signifies the volume of plasma fully freed from the substance by the kidneys in a given time unit. It is usually calculated by the formula $C = \frac{UV}{P}$, where C = clearance in millilitres per minute, U = concentration of the substance in the urine and P = in the plasma, both expressed in the same unit, and V = volume of urine in millilitres per minute.

Glomerular Filtration. — For determination of the glomerular filtration rate there is required a substance that is completely ultrafiltrable, is excreted into the glomerular filtrate in the same concentration as it has in the plasma, and is not reabsorbed or excreted by the tubules. In studies on man these requirements are best fulfilled by inulin. Inulin clearance may therefore be regarded as equal to glomerular filtration rate (Richards, Westfall and Bott 1934, Shannon and Smith 1935, Hendrix, Westfall and Richards 1936, Richards, Bott and Westfall 1938, Miller, Alving and Rubin 1940). It was demonstrated by Ferguson *et al.* (1950) with human subjects that with a decrease in the inulin content of plasma the inulin clearance also declines, and they claimed that this is due to tubular reabsorption of some of the inulin. Eggleton and Habib (1951) reached the same conclusion in their studies on cats and dogs. Laake (1954) also observed in man a decline in the inulin clearance with a decrease in the plasma inulin concentration, but he did not regard this as evidence of reabsorption of inulin by the tubules. The dependence of inulin clearance on the plasma inulin concentration in man was also studied by Shannon and Smith (1935), Miller, Alving and Rubin (1940) and Kennedy and Kleh (1953). In these studies the plasma inulin concentration varied in the ranges 50—400 mg. per 100 ml., 3—96 mg. per 100 ml. and

5—175 mg. per 100 ml. Contrary to the findings in the investigations mentioned above, these marked variations had no effect on the inulin clearance. These investigators regarded this as evidence that the inulin clearance is equal to the glomerular filtration rate.

Renal Blood Flow. — To determine the volume of plasma passing through the kidneys in a given time unit, substances are used that are excreted in maximal amounts into the urine, i.e., by both filtration in the glomeruli and excretion in the tubules. The substance most suitable and practical in use is considered to be para-aminohippuric acid (PAH) in the form of sodium salt (Smith *et al.* 1945, Smith 1951). In order that it would give a clearance value fully identical with the plasma volume passing through the kidneys in a given time unit, all the PAH which enters the kidneys should be excreted into the urine during one passage of blood through the kidneys. In other words, the PAH extraction ratio should be 100 per cent. This has been found to be approximately true provided the PAH concentration in the plasma does not exceed a given limit. Selkurt (1946) found in experiments on dogs that the renal blood flow calculated by means of PAH clearance and haematocrit is 91 per cent of the value obtained by a direct method. The PAH extraction ratio in man has been studied by means of catheterisation of the renal vein and the following values have been obtained in healthy persons: 88 per cent (Warren 1944), 92.5 per cent (Bradley, Curry and Bradley 1947), 90 per cent (Reubi and Schroeder 1949) and 90 per cent (Cargill 1948). In the opinion of Smith (1951), PAH is excreted practically 100 per cent in the functioning kidney parenchyma and the fact that the extraction ratio was only about 90 per cent in the above mentioned studies is due to a part of the blood volume passing from the renal artery into the vein by way of the renal capsule, perirenal fat, renal pelves and other non-excreting tissues. In conformity with the usual terminology, the PAH clearance is termed the renal plasma flow also in the present study, although the »effective renal plasma flow» is actually meant. The PAH extraction ratio is maximal only when the PAH concentration in plasma is below a given level, which depends upon the functional capacity of the tubular cells. This concentration is the »self-depression limit». When it is exceeded the PAH clearance begins to decrease. Chasis *et al.* (1945) regarded as the limit 3—4 mg. per 100 ml., Brun, Hilden and Raaschou

(1947) 7 mg. per 100 ml., and Josephson *et al.* (1952) 11 mg. per 100 ml. The filtration fraction is that portion of the renal plasma flow which is filtered in the glomeruli, i.e., the ratio of inulin clearance to PAH clearance.

Clearance Test Methods. — Smith, Goldring and Chasis (1938), Goldring *et al.* (1940) and Chasis *et al.* (1945) developed a continuous infusion technique for determination of the glomerular filtration rate and the renal plasma flow. It may still be regarded as the most accurate method available (Kleinschmidt 1953), especially for comparing the influence of any given conditions with the control conditions. A rapid priming infusion of high concentrations of inulin and PAH is given into the cubital vein, followed by a slow infusion of dilute solutions of the same substances. When the inulin and PAH concentrations in the plasma have reached a given, approximately constant level, the urinary bladder is emptied by catheterisation. The first sample of urine is discarded. The bladder is then emptied by means of an indwelling catheter at intervals of 15—20 minutes. Complete emptying of the bladder is sought by washing it out with physiological saline. About half-way between the collections of the urine samples a sample is taken of the venous blood. The original clearance test technique has been simplified by, for example, administering the test substances in single injections. In such a case the urine collection periods are begun after the concentrations in the plasma have reached their culmination point. Alving and Miller (1940) observed that following an intravenous injection of inulin the concentration in the plasma, after reaching its peak, declined at first curvilinearly and then rectilinearly. They carried out the inulin clearance determinations during the rectilinear fall of the plasma concentration, which in a healthy person is reached in less than 1 hour.

Sources of Error in Clearance Tests. — When the single injection method is used, the concentration of the test substance after reaching the culmination point is lower in the arteries than in the peripheral veins. After an intravenous injection the inulin concentration in arterial blood averages 7.4 per cent less and the diodrast concentration 28.7 per cent less than that in venous blood drawn from the cubital vein (Brun, Hilden and Raaschou 1949 a). Therefore, venous blood used for the determination in the single injection method will give clearance values below the actual values

(Brun, Hilden and Raaschou 1949 a, Kalant 1950, Kleinschmidt 1953). In studies made by Ferguson *et al.* (1950) the arterio-venous difference in the inulin concentration after a single injection was only in the range +1 per cent to —3 per cent. This difference could be ignored according to Ferguson *et al.* and Laake (1954). The decline in the PAH concentration in the plasma will be less steep if the injection is given intramuscularly and a small amount of adrenalin is added to the PAH (Bucht 1949). The adrenalin addition is naturally to be so small that it will have no effect on the clearance.

»Delay time» is the time necessary for the passage of urine from the kidneys into the bladder. The data reported on the length of the delay period and on the effect of diuresis on this period are diverging. According to Brun, Hilden and Raaschou (1949 a and b) the delay time in man varies from 5 to 15 minutes: the lower the diuresis, the longer the delay time. When diuresis was 1½—5 ml. per minute the delay time was 5—8 minutes. Bojesen (1949) measured the »dead space» in animal experiments, using simultaneously a direct and an indirect method, and observed that the volume of the renal pelvis increases with increasing diuresis except when the latter increase occurs very suddenly. Thus according to his study the error in clearance values arising from the »delay time» cannot be reduced by increasing the diuresis. The same conclusion was reached by McSwiney and de Wardener (1950) in experiments on man. As diuresis increased, the dead space also increased, while the delay time remained constant. The last mentioned varied from 1.3 to 2.8 minutes and averaged 2.1 minutes. When the continuous infusion method is used the delay time has no significance (Kleinschmidt 1953), but in the single injection method it is a source of error, since the corresponding concentrations of test substance in the plasma and in the bladder urine do not coincide in time.

Possibly the most significant source of error, however, is incomplete emptying of the bladder (Smith, Goldring and Chasis 1938). The amount of test substance remaining in the residual urine in the bladder is, of course, the greater the more concentrated the urine is. Owing to this methodical error, a sudden decrease in diuresis reduces and a rise increases the clearance values (Brun, Knudsen and Raaschou 1945). For this reason a good diuresis should be maintained by giving the subject water at regular intervals.

OBJECT OF INVESTIGATION

Although the taking of sauna baths is very common in Finland, only few observations have been made of its effect on kidney function. These observations relate to the volume of urine excreted during the sauna bath. It would, however, be useful to obtain an idea of the effect of this bath on certain other renal functions. Many patients with diseases of various kinds continue to use sauna baths also after onset of their disease and it is not always possible to state whether this is beneficial or harmful. A systematic investigation on the effect of the sauna bath on the renal function in healthy persons can lay the basis for subsequent studies of its effect on renal function in various diseases.

Since the function of the kidneys is greatly dependent on numerous extrarenal factors and on changes occurring in the latter, the subject of the present investigation has not been limited to the kidneys only. A sauna bath, because of the profuse sweating which it evokes, produces changes in the fluid balance of the organism which may possibly influence the renal functions. As the subjects of investigation were therefore selected the excretion of water, sodium, chloride and potassium in sweat and urine, and the renal haemodynamics before and during the sauna bath. Using renal clearance tests, determinations were made of the glomerular filtration rate and the renal plasma flow, and calculations were performed concerning the mechanism of sodium and chloride excretion.

MATERIAL AND METHODS

TEST SUBJECTS

The experiments were carried out on 40 healthy male subjects aged 20—48 years, all of whom were accustomed to the Finnish sauna bath. For the purposes of this investigation the test subjects were divided into three groups. Those in groups I and II were subjected to a careful examination of their general physical condition, which in addition to the case history and a clinical examination included micro-roentgenography of the thorax, electrocardiography, and determinations of the erythrocyte sedimentation rate, haemoglobin, non-protein nitrogen and urinary sediment, albumin and glucose. In group III, also, the case histories and a clinical examination showed that the test subjects were in good health.

On 6 persons the renal clearance tests were made by the single injection technique (group I). There were 14 persons whose renal clearances were determined by the continuous infusion technique, and the sodium, chloride and potassium concentrations in the urine, sweat and plasma were determined (group II). Twenty persons were examined for the sodium, chloride and potassium excretions in urine and sweat when no water or sodium chloride was given to them during the experiment (group III). Variations in the plasma potassium were followed in 8 of these persons during the sauna bath.

Thus the renal clearance tests were carried out on 20 persons and the electrolyte determinations on 34 persons before and during a Finnish sauna bath.

PERFORMANCE OF THE EXPERIMENTS

All the experiments were carried out during the forenoon and midday. The subjects were in a recumbent position throughout the

experiment, with the exception of taking a few steps from the dressing-room of the sauna into the hot-room. The sauna bath was limited to its most typical phase, *i.e.*, sweating in the hot, dry air. No water was thrown on the hot stone pile on the furnace, since higher humidity would have rendered the experiment too strenuous. The dry bulb and wet bulb temperatures were measured with a Sling psychrometre at the level at which the test subject was lying. Before the subject entered the hot-room his rectal or axillary temperature was measured to assure that the body temperature was normal. At the end of the bath his rectal temperature was again measured while he was still lying on the platform. The amount of sweat excreted in the sauna was determined by calculating the loss of body weight during the bath, taking also into consideration the volume of fluid administered orally or parenterally and the volume of urine excreted.

Examination of the Sweat. — When the sweat is allowed to freely evaporate from the skin, the correct sodium, chloride and potassium concentrations of the sweat excreted during the sauna bath cannot be obtained by merely analysing the sweat collected from the skin. The following indirect method was therefore employed. The skin was carefully cleaned under a shower before the experiment was started. The test person then walked into the hot sauna room and lay down on the highest platform, on which there previously had been placed a plastic sheet for collection of the sweat. The edges of the sheet were held up by supports. At the end of the bath, when the subject was still lying on the platform, the whole body was rinsed with 3—4 litres of distilled water, which was allowed to flow off on the plastic sheet. The fluid was carefully collected and measured and a sample was taken for analysis. The calculated loss of each electrolyte, expressed in mEq., was divided by the loss of body weight in the sauna to obtain the sodium, chloride and potassium concentrations in mEq./l.

Determination of Urinary Sodium, Chloride and Potassium. — In group II the urine samples were collected through an indwelling catheter, which was necessary in order to obtain also the samples for the renal clearance tests. Two or three samples were taken before the subject entered the sauna hot-room and 3 samples were taken in the latter. Emptying of the bladder was assured by rinsing it with a measured volume of distilled water. Allowance was

made for this added volume of water in calculating the true urinary concentrations of sodium, chloride and potassium (mEq./l.) from the values obtained in the analyses. The urinary excretion rates of sodium, chloride and potassium were also calculated (μEq./min.) In group II it was possible to calculate the filtration rates and reabsorptions of sodium and chloride with the aid of the glomerular filtration rate and the urinary and plasma electrolyte concentrations (Pitts and Alexander 1944). In making these calculations, the slight error arising from the protein in the plasma and from Donnan's effect (Black 1952) was ignored. Similar calculations on the mechanism of potassium excretion could not be carried out since potassium is both reabsorbed and secreted by the tubules (Berliner and Kennedy 1948, Mudge, Foulks and Gilman 1948 and 1950, Leaf and Camara 1949, Berliner, Kennedy and Hilton 1950, Berliner, Kennedy and Orloff 1951, Sirota and Kroop 1951, Evans *et al.* 1954, Black and Emery 1957). The subjects in group II were given a large amount of water to drink in order to maintain adequate diuresis for the clearance tests, and a continuous infusion of physiological saline was administered to them. Since this may have influenced the electrolyte balance, the effect of the sauna bath on the electrolyte excretion was also studied in test subjects (group III) who received no drinking water or saline infusion. Since diuresis in the latter group was low and the urine was voided spontaneously, only one sample was obtained before the bath and one during the bath.

Plasma Sodium, Chloride and Potassium Concentration. — The blood samples were taken without stasis from the cubital vein through an indwelling cannula using heparin as anticoagulant, and the plasma was separated as soon as possible. In group II the plasma electrolyte concentrations were determined from samples taken before and at the end of the sauna bath. In group III the course of the plasma potassium concentration was observed from blood samples taken at intervals of 10 minutes.

Renal Clearance Tests. — Inulin and PAH clearance tests were made in groups I and II.

The para-aminohippuric acid used in the PAH clearance tests was »Nephrotest» (Cassella Farbwerke). The inulin solution was prepared from powdered »Inulin album purissimum» (Merck). Since, however, experiments with rabbits revealed the presence of pyrogens, the hot solutions were

passed through a Seitz asbestos EK or EKS filter (Co-Tui *et al.* 1937, Wilke and Voss 1954). Each batch prepared in this way was tested on rabbits for pyrogens. No pyrogenic reactions occurred in any of the test persons. The inulin clearance tests on the last 4 subjects were made with »Inulin purissimum pyrogenfrei» (Laevosan-Gesellschaft), which was obtainable in sterile, pyrogen-free ampoules.

Before and during the experiment the subjects were allowed to drink water frequently at regular intervals in order to maintain a moderately high and even diuresis. It was not considered necessary to have the urine collection periods of equal length, but the exact times of sample taking were noted down. The blood samples were taken at about the middle of each period and the necessary correction in timing was made with the aid of a graph, as done by Chasis *et al.* (1945). The bladder was emptied just before the subject entered the sauna hot-room. However, a residual of the urine excreted by the kidneys prior to this remained in the upper urinary tract and became mixed later in the bladder with the urine excreted by the kidneys in the sauna. The first urine collection period in the sauna hot-room is therefore a transition period. Since during the greater part of it the skin was still dry, it is called the »latent period» and the subsequent periods »sweating periods». On an average, the latent period ended 16 minutes, and »sweating period I» 33 minutes after the subject entered the hot-room. Sweating period I is considered to represent best the changes produced in kidney function by the usual Finnish sauna bath. The changes during sweating period II are believed to correspond to those produced by a longer stay in the sauna bath.

Group I. — Single injections of inulin and PAH were given at the beginning of the experiment. Using the Bucht (1949) method, 13—16 ml. of a 20 per cent solution of PAH to which was added one-half of the same volume of a 2 per cent solution of »Xylocain-Exadrin» (Astra) were given intramuscularly. This was followed 5—10 minutes later by an intravenous injection of 90—110 ml. of 10 per cent inulin during about 10 minutes. The urine samples were obtained spontaneously, the subject being requested to empty the bladder as thoroughly as possible. The urine collection periods were started 45—55 minutes after the PAH injection. The number of periods in this group was usually smaller than that in the group given a continuous infusion.

Group II. — After the blood sample was taken from the cubital vein, a single injection of 1—2 gm. of inulin and 0.8 gm. of PAH in 14—24 ml. of physiological saline was given intravenously during 1—2 minutes. This

was followed immediately by a continuous drip infusion containing 7—8 gm. of inulin and 3.2 gm. of PAH in 500 ml. of physiological saline. The infusion was continued at an even rate of about 2 ml· per minute throughout the experiment, i.e., both before entry into the hot-room and during the stay there. A total of 300—500 ml. of infusion solution per person was consumed during the experiment.

For taking of the urine samples the catheter was introduced into the bladder and fixed in position with tube gauze so that its upper end was well past the internal urethral orifice but did not enter unnecessarily far into the bladder, to ensure as complete emptying as possible. About 30—40 minutes after commencement of the infusion, the bladder was emptied and rinsed with a measured volume of sterile distilled water. This volume varied from 20 to 100 ml. according to diuresis. The test periods began at this moment. There were 2—3 periods before the subject entered the hot-room and 3 periods in the hot-room, each period lasting 12—25 minutes. The catheter remained in position when the subject walked into the hot-room. In the hot-room the infusion tube passed through a vessel of cold water to prevent heating of the infusion solution. The temperature of the cooling water was controlled.

CHEMICAL ANALYSES

The *sodium and potassium* determinations were made with the Beckmann B flame photometre using the method of Smit, Alkemade and Verschure (1951), Hunter (1951) and Hilgers (1953).

The *chloride* was determined by the mercurimetric titration method (Brun 1949).

Inulin. — The proteins were first precipitated with zinc sulphate and sodium hydroxide (Somogyi 1930). The inulin was then hydrolysed in a protein-free filtrate using hydrochloric acid to form fructose. The fructose reacted with resorcinol in the presence of thiourea and glacial acetic acid when kept in the water bath at 80°C for 10 minutes. A red colour was produced (Seliwanoff's reaction), the intensity of which was measured in the Beckmann B spectrophotometre, using wave length 520 mμ. Control determinations of standard solutions were made for each batch of samples. The method used in the inulin determinations was that developed by Roe (1934), Steinitz (1938), Hubbard and Loomis (1942) and Roe, Epstein and Goldstein (1949).

Para-Aminohippuric Acid. — After precipitation of the proteins with cadmium sulphate and sodium hydroxide (Smith *et al.* 1945), the free amino group of PAH in the protein-free filtrate

was diazotised with nitrous acid and the excess nitrite was removed by the addition of ammonium sulphamate. The diazotised PAH was coupled with N-(1-naphthyl)-ethylenediaminedihydrochloride to form an azo compound with a purplish-red colour (Bratton-Marshall reaction). The analyses were carried out using the modification of Smith *et al.* In connection with each set of samples the standard solutions also were analysed. The colour intensities were measured in the Beckmann B spectrophotometre at wave length 540 mμ.

STATISTICAL TREATMENT

In analysing the changes taking place in the sauna bath, the decrease or increase in each variable was computed separately for each individual. The mean of these changes represents the average effect of the sauna bath. Statistical significance, or the question whether the average change essentially deviates from zero, was tested by applying *Student's t*-test. If the individual changes are denoted by Δ, then the standard error $s_{\bar{\Delta}}$ of the mean change $\bar{\Delta}$ is estimated by the formula

$$(1) \qquad s_{\bar{\Delta}} = \sqrt{\left[\Sigma \Delta^2 - \frac{(\Sigma \Delta)^2}{n}\right] / n(n-1)},$$

where n stands for the number of observations. Now the t-variable is calculated by dividing the mean change by its estimated standard error, thus:

$$(2) \qquad t = \bar{\Delta} / s_{\bar{\Delta}}.$$

By consulting appropriate statistical tables provided, for example, by Fisher and Yates (1953), the probability P, defined in the following, can be determined. P is the tabular value of the probability that chance alone would produce a t-value as large as or larger than that actually observed. If this probability is sufficiently small, the possibility of mere chance can be neglected, and the observed mean change is said to be statistically significant. In this paper, probabilities equal to or larger than 0.1 are considered too large, and their numerical values have been replaced by a pair of dots (. .).

In the case of comparing two mean changes, say $\bar{\Delta}_1$ and $\bar{\Delta}_2$, the difference $\delta = \bar{\Delta}_1 - \bar{\Delta}_2$ between them is first computed. The

standard error of this difference is, with sufficient accuracy, estimated by the formula

$$(3) \qquad s_\delta = \sqrt{s^2_{\bar{\Delta}_1} + s^2_{\bar{\Delta}_2}}.$$

Again, the difference δ can be tested with the t-test in full analogy with the test concerning mean changes.

For the sake of economy in computations, formula (1) was in most cases replaced by a short-cut method described by Noether (1955). This method is based on ranges of variation R in subsamples of suitable size. For example, if there are 14 individuals, the material is divided into two sub-samples of 7 individuals each. In both sub-samples the range, say R_1 and R_2, is determined, whereafter the standard error is quickly estimated by

$$(4) \qquad s_{\bar{\Delta}} = a_n(R_1 + R_2)/\sqrt{n}.$$

In the formula, a_n stands for a tabulated constant multiplier for samples of n individuals. Noether has shown that the loss of accuracy in applying (4) instead of (1) is unimportant, particularly in consideration of the saving in computation work.

In some cases the dependence between two concomitant variables was analysed statistically. The model adopted for the purpose is the common linear regression. In this model, the variable x_0 is considered »dependent» on the »independent» variable x_1, the relationship between the two being approximately

$$(5) \qquad x_0 \simeq a + bx_1,$$

where a and b are constants, the regression coefficient b indicating the slope of the regression line. This line is fitted with the observed points so that the residual sum of squares (sum of squared vertical deviations of points from the line) is as small as possible. The formula for b is

$$(6) \qquad b = (\Sigma x_0 x_1 - \Sigma x_0 \Sigma x_1/n)/(\Sigma x^2_1 - (\Sigma x_1)^2/n).$$

and for a

$$(7) \qquad a = \bar{x}_0 - b\bar{x}_1.$$

In tabulating the final results the numerical values of some statistical characteristics have been rounded off. However, computation of the tests has been performed by using the figures before rounding.

RESULTS

As is seen from table 3, the hot-room temperature in the sauna and the time spent in it varied somewhat in the different experiments. In groups I and II the effect of the bath on the renal function was observed periodically. These groups therefore spent a longer time in the sauna than group III, in which only one urine sample was taken in the sauna. The rectal temperature taken towards the end of the bath showed marked individual differences (table 3).

TABLE 3

SAUNA HOT-ROOM TEMPERATURES, TIME SPENT IN SAUNA, RECTAL TEMPERATURE AT END OF BATH, AND AMOUNT OF SWEAT

Group I: Test subjects drank water;
Group II: Test subjects drank water and received physiological saline solution parenterally;
Group III: Test subjects had neither water nor saline.

Statistics	Sauna Temperatures		Time Spent in Sauna,	Rectal Temperature in Sauna,	Amount of Sweat,
	Dry Bulb, °C	Wet Bulb, °C	min.	°C	gm.
Group I					
Mean	68	35	48	38.2	700
Range	62—75	31—42	30—57	37.4—39.0	430— 900
Group II					
Mean	67	37	58	38.3	990
Range	54—74	30—49	41—76	37.0—39.4	480—1580
Group III					
Mean	73	38	28	38.2	740
Range	64—80	34—49	16—47	37.7—39.0	100—2000

The test subjects endured the sauna bath very well in general. Some subjects complained of orthostatic dizziness when rising up from the reclining posture at the end of the experiment and walking away from the hot-room. There was one case of complication during the experiment. One of the mem-

bers of group III breathed with a panting respiration while in the sauna, leading to a typical, mild hyperventilation tetany. The blood alkali reserve declined from 25.5 per cent to 22.2 per cent by vol. No essential change occurred in the plasma calcium (10.2 mg. per 100 ml. before the sauna bath and 9.9 mg. per 100 ml. at the end of the bath). When the subject held his breath and cold water was dashed on his body, the symptoms of tetany passed within a few minutes.

AMOUNT OF SWEAT AND THE SWEAT SODIUM, CHLORIDE AND POTASSIUM CONTENTS

The amount of sweat is shown in table 3, and the sodium, chloride and potassium concentrations of sweat are given in table 4.

TABLE 4

SODIUM, CHLORIDE AND POTASSIUM CONCENTRATIONS OF SWEAT, AND AMOUNTS OF SODIUM, CHLORIDE AND POTASSIUM LOST IN SWEAT DURING SAUNA BATH

Group II: Test subjects received water and physiological saline solution
Group III: Test subjects received no water or salt

Statistics	Na, Cl and K Concentrations in Sweat, mEq./l.			Na, Cl and K Losses in Sweat, mEq.		
	Sodium	Chloride	Potassium	Sodium	Chloride	Potassium
Group II						
Mean	28	26	3.5	29	27	3.5
Range	9—56	9—56	2.7—5.1	7—54	10—54	1.9—7.1
Group III						
Mean	39	32	4.7	26	22	2.8
Range	13—70	14—60	2.0—14.8	6—65	5—68	1.0—6.1

The amount of sweat excreted in the sauna varied greatly according to the individual. In group III the smallest sweat loss was 100 gm. and the highest 2,000 gm. with an average of 740 gm. The electrolyte content of the sweat collected from the whole body also showed marked individual differences. The sodium content averaged 39 mEq./l., the chloride content 32 mEq./l. and the potassium content 4.7 mEq./l. The amounts of sodium, chloride and potassium lost in the sweat during the sauna bath are shown in table 4. As is seen, they were subject to great variations.

From fig. 1 it is observed that the sodium and chloride losses in sweat showed a good correlation. The same correlation was, of course, seen between the concentrations of sodium and chloride in

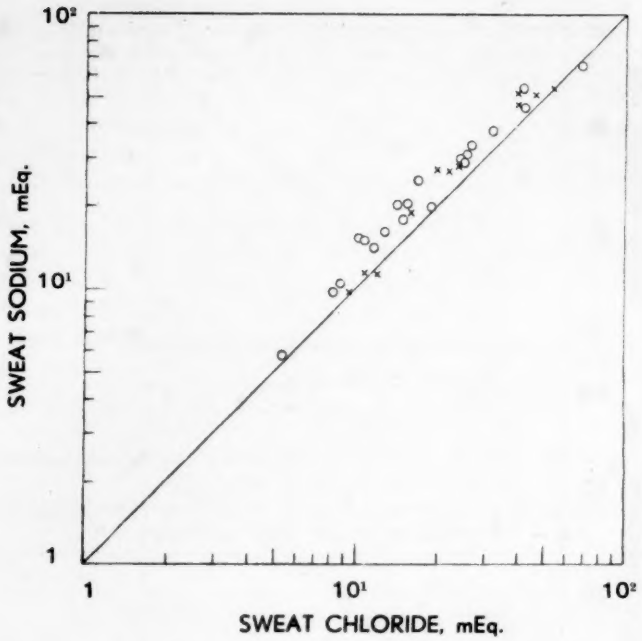

Fig. 1. — Graph showing the correlation of the sodium and chloride losses in sweat in the sauna. Log. scales. A good correlation is seen.

× = Test subjects given water and sodium chloride during the experiment (group II)
O = Test subjects receiving none (group III)

the sweat. The smallest loss of sodium and chloride in fig. 1 is equivalent to 0.3 gm. and the highest loss to 3.8 gm. of sodium chloride. Fig. 2 indicates that the greater the amount of sweat, the higher the sodium, chloride and potassium losses in the sweat.

DIURESIS AND THE URINARY SODIUM, CHLORIDE AND POTASSIUM CONTENTS

Diuresis and the urinary electrolyte concentrations in the sauna were dependent on whether or not fluids were given during the experiment. In group II, in which the subjects were given water and salt during the experiment, no consistent change was demonstrable in the diuresis or in the urinary sodium, chloride and potassium concentrations in the sauna, as is seen in tables 5 and 6.

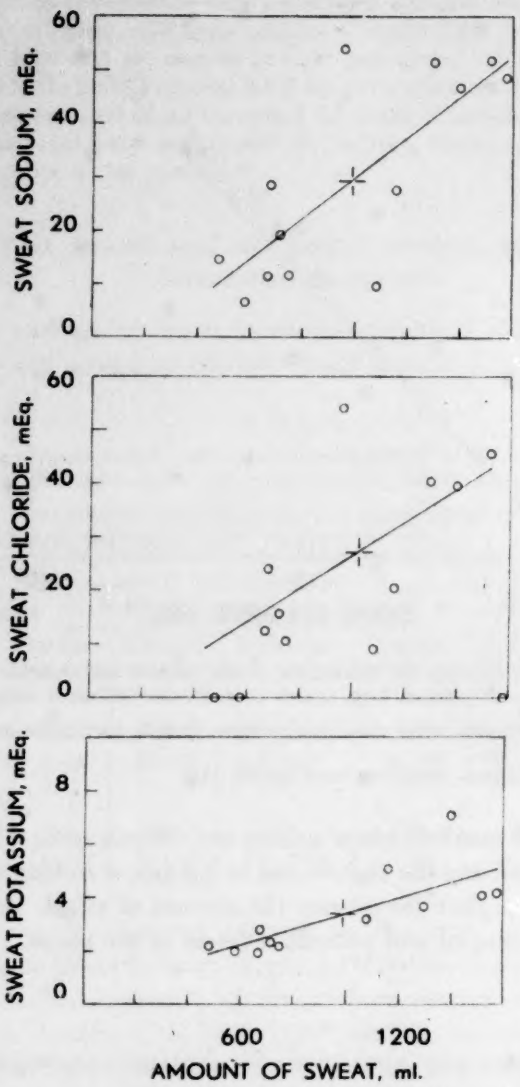

Fig. 2. — Graphs showing the correlation of the amount of sweat in the sauna and the sodium, chloride and potassium losses in sweat, together with regression lines expressing the average relation for test subjects given water and sodium chloride during the experiment (group II). Regression line reveals evident correlation between the variables studied. Equation of the regression line for the sodium loss is $x_0 = 0.038\,x_1 - 8.25$, for the chloride loss $x_0 = 0.031\,x_1 - 4.54$, and for the potassium loss $x_0 = 0.003\,x_1 + 0.44$.

TABLE 5

DIURESIS BEFORE SAUNA AND IN SAUNA IN GROUP II

Test subjects were given water and physiological saline solution. All changes in the sauna are calculated from the values before the sauna.

Statistics		Before Sauna	In Sauna		
			Latent Period	Sweating Periods	
				I	II
Mean	ml./min.	7.3	6.3	3.8	2.7
Range	»	0.5—16.8	1.0—11.2	0.1—10.4	0.5—10.0
Mean change	»	.	—1.5	—3.5	—4.6
Standard error of mean change	»	.	1.4	1.7	1.7
t		.	1.08	2.13	2.64
P		.	..	..	0.05

TABLE 6

SODIUM, CHLORIDE AND POTASSIUM CONCENTRATIONS OF URINE BEFORE SAUNA AND IN SAUNA IN GROUP II

Test subjects received water and saline solution. All changes in the sauna are calculated from the values before the sauna.

Statistics		Before Sauna	In Sauna		
			Latent Period	Sweating Periods	
				I	II
Sodium concentration					
Mean	mEq./l.	107	65	124	69
Range	»	22—273	12—241	3—1050	6—222
Mean change	»	.	—34	+17	—38
Standard error of mean change	»	.	15	61	21
t		.	2.22	0.28	1.77
P		.	0.05	..	..
Chloride concentration					
Mean	mEq./l.	104	77	131	90
Range	»	15—260	15—252	9—1004	20—243
Mean change	»	.	—24	+28	—14
Standard error of mean change	»	.	17	60	23
t		.	1.43	0.46	0.62
P		.	..	..	..
Potassium concentration					
Mean	mEq./l.	67	32	111	75
Range	»	4—460	3—101	9—1032	16—218
Mean change	»	.	—3	+44	+8
Standard error of mean change	»	.	6	38	28
t		.	0.49	1.16	0.27
P		.	..	..	..

On the other hand, in group III, in which the subjects received no water or salt, the diuresis decreased significantly in the sauna, as shown in table 7 and fig. 3.

TABLE 7

DIURESIS BEFORE SAUNA AND IN SAUNA IN GROUP III

Test subjects were given no water or salt.

Statistics		Before Sauna	In Sauna
Mean	ml./min.	0.8	0.5
Range	»	0.3—2.3	0.0—1.1
Mean change	»	.	—0.4
Standard error of mean change	»	.	0.1
t	.	.	3.03
P	.	.	0.01

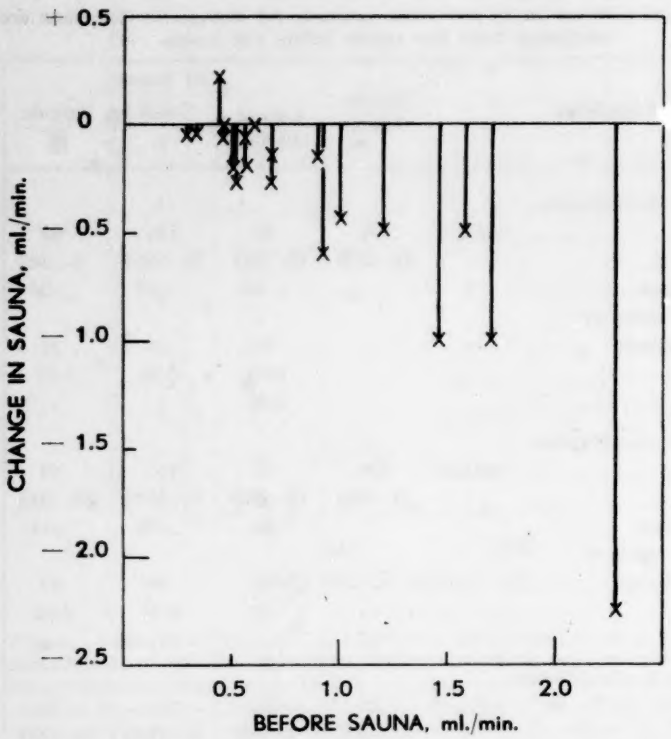

Fig. 3. — Graph showing the diuresis before the sauna bath and the changes occurring in the sauna in test subjects receiving no water or salt during the experiment (group III). Diuresis decreased significantly in the sauna.

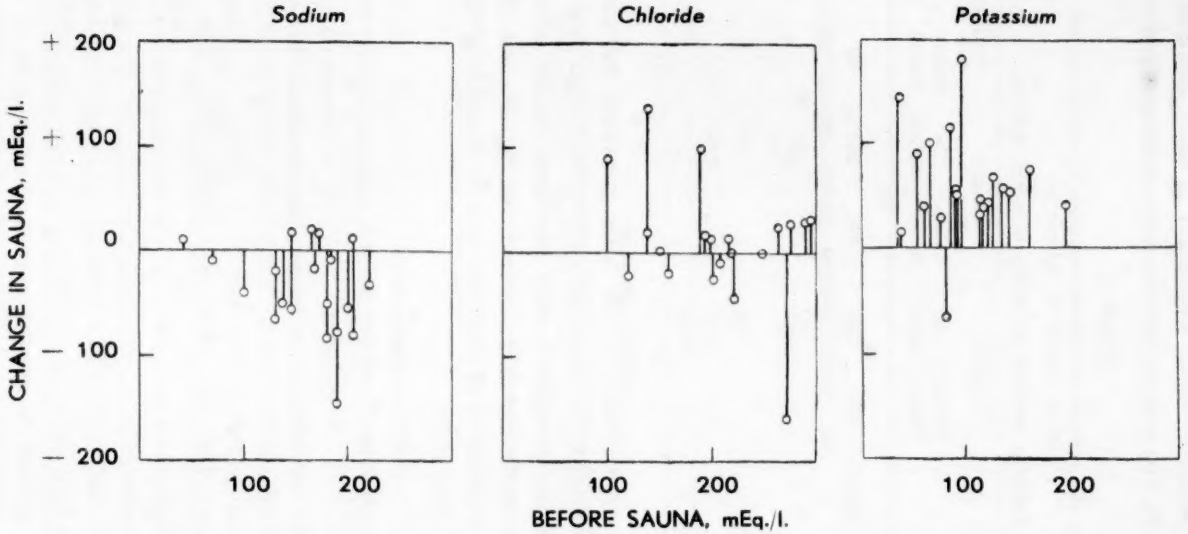

Fig. 4. — Graphs showing the sodium, chloride and potassium concentrations of the urine before the sauna and changes occurring in the sauna in test subjects receiving no water or salt (group III). The sodium concentration declined significantly, the chloride concentration showed no change, and the potassium concentration increased significantly in the sauna.

The sodium concentration of the urine declined somewhat in the sauna, the difference being significant at the 1 per cent level (table 8 and fig. 4). The urinary chloride did not change significantly.

TABLE 8

SODIUM, CHLORIDE AND POTASSIUM CONCENTRATIONS OF URINE BEFORE SAUNA AND IN SAUNA IN GROUP III

Test subjects received no water or saline solution.

Statistics	Sodium		Chloride		Potassium	
	Before Sauna	In Sauna	Before Sauna	In Sauna	Before Sauna	In Sauna
Mean ..... mEq./l.	158	123	204	215	99	160
Range ..... »	42—220	45—218	100—294	97—326	36—194	14—275
Mean change .. »	.	—35	.	+11	.	+61
Standard error of mean change »	.	10	.	13	.	11
t	.	3.67	.	0.86	.	5.40
P	.	0.01	.	..	.	0.001

The potassium concentration in the urine increased definitely in the sauna and the difference was significant at the 0.1 per cent level. The urinary potassium/sodium ratio increased in the sauna in both groups to nearly two-fold (table 9 and fig. 5). The change was significant in group II at the 1 per cent level and in group III at the 0.1 per cent level.

TABLE 9

URINARY POTASSIUM/SODIUM RATIO BEFORE SAUNA AND IN SAUNA

Statistics	Group II		Group III	
	Before Sauna	In Sauna	Before Sauna	In Sauna
Mean	0.55	1.26	0.63	1.62
Range	0.10—2.43	0.31—6.00	0.28—2.01	0.09—4.29
Mean change	.	+0.71	.	+0.96
Standard error of mean change ..	.	0.21	.	0.20
t	.	3.33	.	4.91
P	.	0.01	.	0.001

In group II (table 10) the excretion rate of sodium in the urine decreased in the sauna with each successive period, and during period II the average excretion rate was only one-third of that before

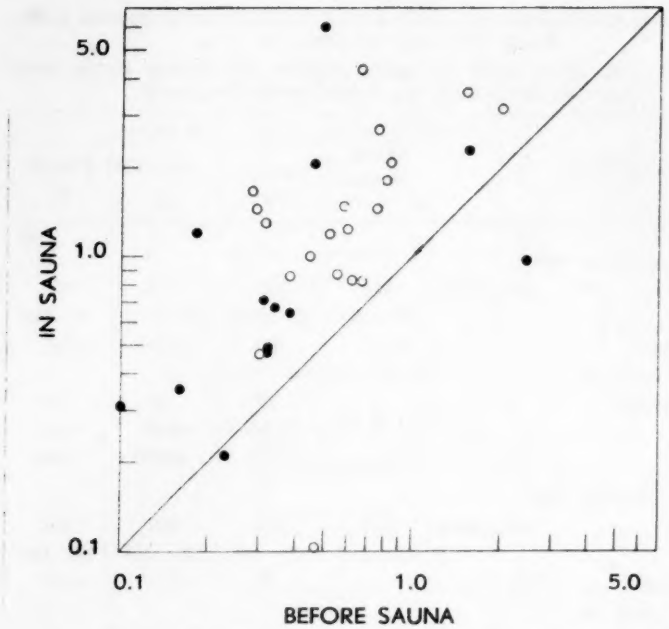

Fig. 5. — Graph showing the potassium/sodium ratio in the urine before the sauna and in the sauna. in groups II und III. Log scales. In both groups the potassium/sodium ratio increased significantly in the sauna.

● = Test subjects given water and sodium chloride during the experiment (group II)
○ = Test subjects given none (group III).

the sauna. The decline in the sodium excretion rate was significant during the latent period at the 2 per cent level and during the sweating periods at the 0.1 per cent level. The results are shown in fig. 6. The urinary excretion rate of chloride did not yet change significantly during the latent period. During the sweating periods the average chloride excretion rate decreased to one-half of the excretion rate before the sauna. The decrease during the sweating periods was significant at the 1 per cent level (table 10 and fig. 7). The urinary excretion rate of potassium in the sauna underwent an exceptional change. In cases in which it was low before the sauna (below 88 μEq./min.) it increased, and when high before the sauna (over 88 μEq./min.) it decreased (table 10 and fig. 8). The urinary excretion rates of sodium, chloride and potassium in group III are shown in table 11 and fig. 9. The results were similar to those seen in the preceding group.

TABLE 10

URINARY SODIUM, CHLORIDE AND POTASSIUM EXCRETION RATES BEFORE SAUNA AND IN SAUNA IN GROUP II

Test subjects were given water and saline solution. All changes in the sauna are calculated from the values before the sauna.

Statistics	Before Sauna	In Sauna		
		Latent Period	Sweating Periods	
			I	II
Sodium excretion rate				
Mean ..... μEq./min.	314	256	143	103
Range ..... »	70—606	95—503	13—271	3—222
Mean change ..... »	.	—58	—170	—211
Standard error of mean change .... »	.	20	36	41
t	.	2.93	4.69	5.12
P	.	0.02	0.001	0.001
Chloride excretion rate				
Mean ..... μEq./min.	301	279	189	154
Range ..... »	53—574	98—501	36—429	14—346
Mean change ..... »	.	—22	—111	—147
Standard error of mean change .... »	.	17	32	36
t	.	1.32	3.53	4.07
P	.	..	0.01	0.01
Potassium excretion rate				
Mean ..... μEq./min.	112	105	92	89
Range ..... »	34—280	37—205	58—121	37—131
Mean change ..... »	.	—6	—20	—22
Standard error of mean change .... »	.	15	16	21
t	.	0.43	1.22	1.08
P	.	..	..	..

TABLE 11

URINARY SODIUM, CHLORIDE AND POTASSIUM EXCRETION RATES BEFORE SAUNA AND IN SAUNA IN GROUP III

Test subjects received no water or saline solution.

Statistics	Sodium		Chloride		Potassium	
	Before Sauna	In Sauna	Before Sauna	In Sauna	Before Sauna	In Sauna
Mean ..... μEq./min.	135	64	168	103	82	73
Range ..... »	48—431	1—190	61—613	2—214	25—286	4—157
Mean change.. »	.	—71	.	—64	.	—9
Standard error of mean change »	.	22	.	31	.	16
t	.	3.27	.	2.09	.	0.60
P	.	0.01	.	0.05	.	..

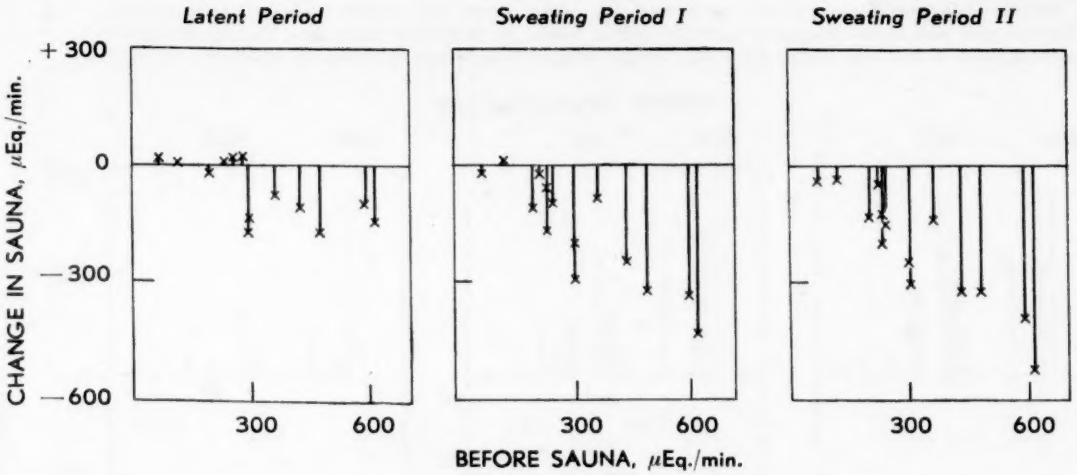

Fig. 6. — Graphs showing the sodium excretion rate in the urine before the sauna and the changes occurring during successive periods in the sauna in test subjects receiving water and salt (group II). All values before the sauna are means of 2 or 3 periods. Comparisons in each period in the sauna are made with the pre-sauna values. The urinary sodium excretion rate decreased significantly during all periods.

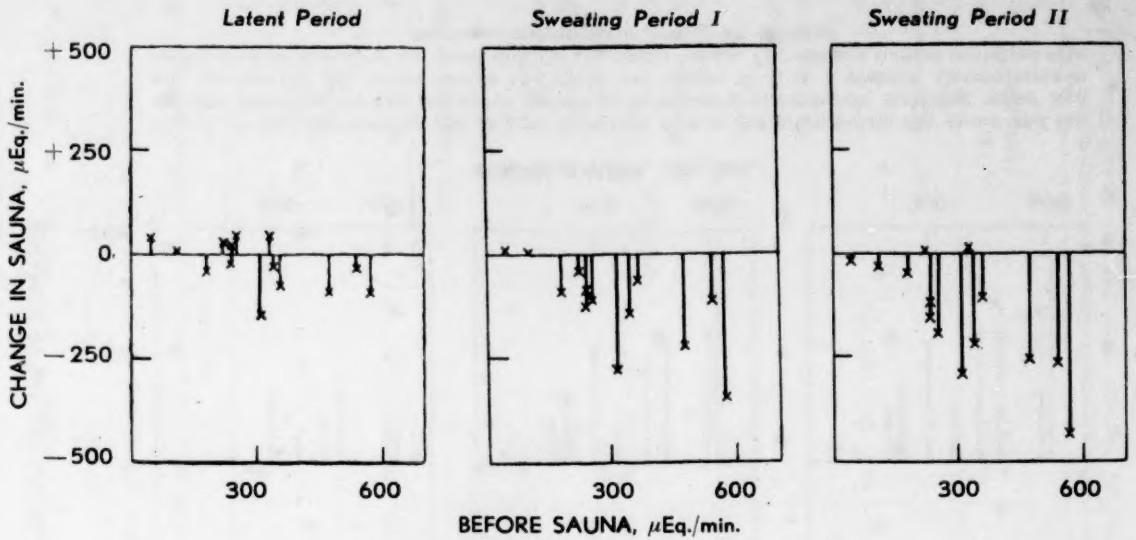

Fig. 7. — Graphs showing the chloride excretion rate in the urine before the sauna and the changes occurring during successive periods in the sauna in test subjects receiving water and salt (group II). Comparisons in each period are made with the pre-sauna values. No significant change was observed in the urinary chloride excretion rate during the latent period but there was a significant decrease during periods I and II.

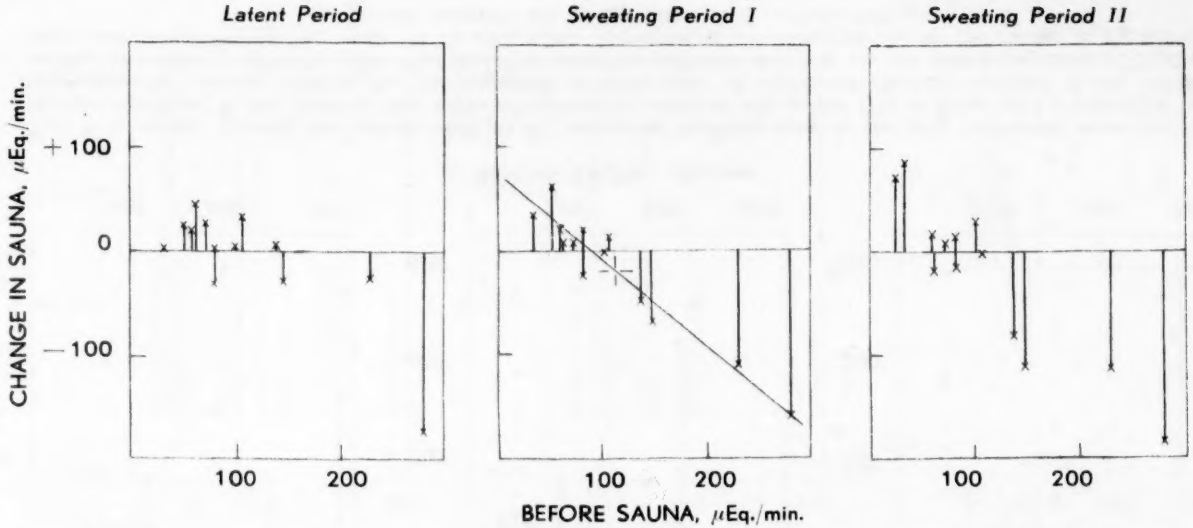

Fig. 8. — Graphs showing the potassium excretion rate in the urine before the sauna and the changes occurring during successive periods in the sauna in test subjects receiving water and salt (group II), together with a regression line expressing the average relation during period I. An increase was seen in the urinary potassium excretion in the sauna if it was low before the sauna ($<$ 88 μEq./min.), and a decrease if it was high ($>$88 μEq./min.). Equation of the regression line for the change in the urinary potassium excretion rate during sweating period I is $x_0 = 73.3 - 0.83\ x_1$.

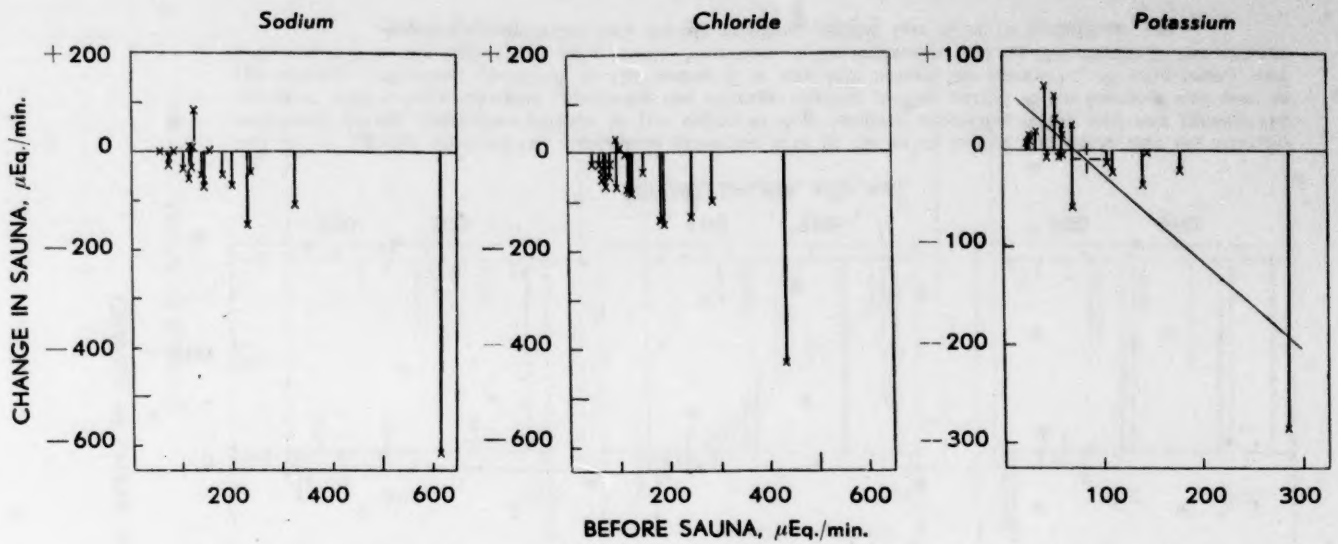

Fig. 9. — Graphs showing the sodium, chloride and potassium excretion rates in the urine before the sauna and the changes occurring in the sauna in test subjects receiving no water or salt (group III), together with a regression line expressing the average relation for the potassium excretion rate. A significant decrease occurred in the urinary sodium and chloride excretion rates. The potassium excretion rate increased if it was low before the sauna (<72 μEq./min.) and decreased if it was high (>72 μEq./min.). Equation of the regression line for the change in the urinary potassium excretion rate in the sauna is $x_0 = 65.5 - 0.91\ x_1$.

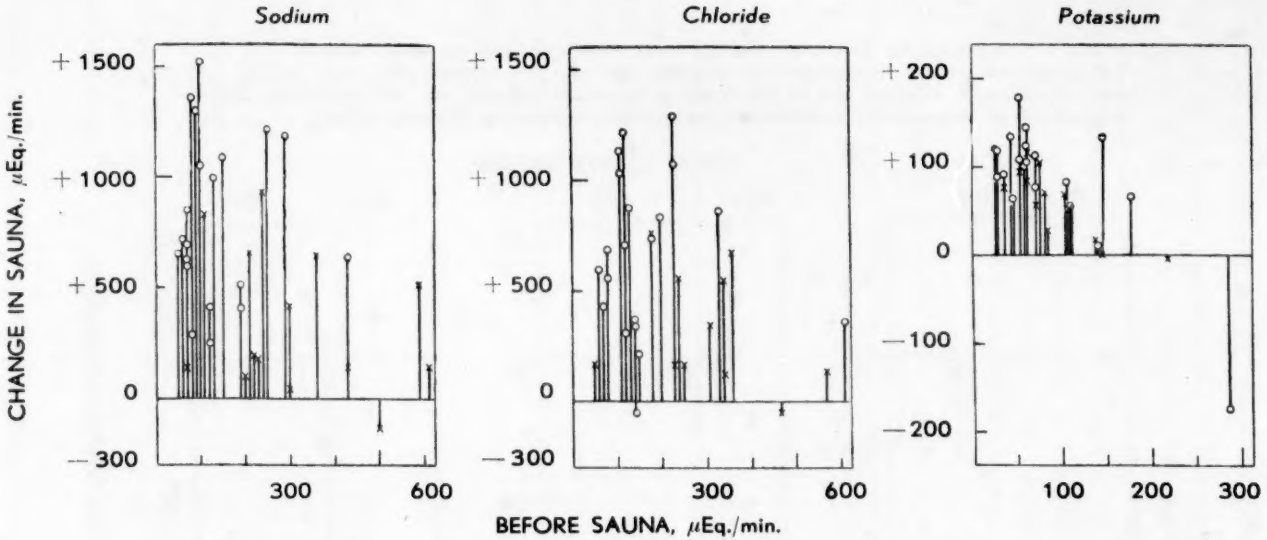

Fig. 10. — Graphs showing total losses of sodium, chloride and potassium before the sauna and the changes occurring in the sauna. Total loss before sauna = loss in the urine; total loss in sauna = loss in urine + loss in sweat. A significant increase occurred in the sauna in the total losses of all the electrolytes studied.

× = Test subjects given water and salt during the experiment (group II)
O = Test subjects given none (group III).

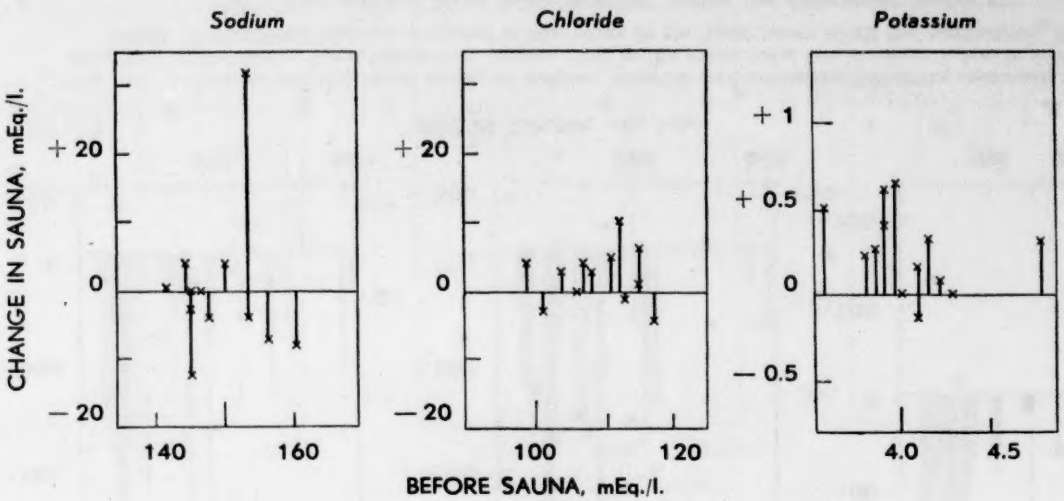

Fig. 11. — Graphs showing the sodium, chloride and potassium concentrations of the plasma before the sauna and the changes occurring in the sauna in test subjects given water and salt (group II). The plasma sodium and chloride concentrations showed no significant change, whereas the potassium concentration increased significantly.

TOTAL SODIUM, CHLORIDE AND POTASSIUM LOSSES

In this investigation the total loss of electrolytes constitutes the loss in urine before the sauna bath, and the loss in both urine and sweat in the sauna. The results are shown in table 12 and fig. 10. Marked individual variations were found in the total amounts of sodium, chloride and potassium lost. In the sauna the total losses usually showed manyfold increases. The changes were significant at the 1 per cent and 0.1 per cent levels, as is seen in table 12.

TABLE 12

TOTAL LOSSES OF SODIUM, CHLORIDE AND POTASSIUM BEFORE SAUNA AND IN SAUNA

Total loss before sauna = loss in the urine; total loss in sauna = loss in urine + loss in sweat. Test subjects in group II were given water and saline solution; group III received none.

Statistics	Sodium		Chloride		Potassium	
	Before Sauna	In Sauna	Before Sauna	In Sauna	Before Sauna	In Sauna
Group II						
Mean ....μEq./min.	312	659	322	651	95	155
Range .... »	70—606	214—1171	54—573	221—1082	34—229	110—227
Mean change »	.	+347	.	+328	.	+60
Standard error of mean change .. »	.	86	.	76	.	11
t	.	4.01	.	4.29	.	5.26
P	.	0.01	.	0.01	.	0.001
Group III						
Mean .. μEq./min.	135	955	168	844	82	171
Range .... »	62—431	360—1624	61—613	88—1519	27—286	110—280
Mean change »	.	+820	.	+676	.	+89
Standard error of mean change .. »	.	84	.	82	.	16
t	.	9.77	.	8.30	.	5.51
P	.	0.001	.	0.001	.	0.001

PLASMA SODIUM, CHLORIDE AND POTASSIUM CONCENTRATIONS

Table 13 and fig. 11 show that in group II there were no significant changes in the plasma sodium and chloride concentrations in the sauna. The mean potassium concentration of the plasma in-

creased from 4.0 mEq./l. before the sauna to 4.3 mEq./l. in the sauna. The increase in the sauna was significant at the 1 per cent level in group II, in which the potassium analyses were made only from blood samples taken immediately before the sauna bath and towards the end of the bath (table 13 and fig. 11). Blood samples for potassium analyses were taken from 8 subjects in group III at intervals of 10 minutes. As is observed from fig. 12, the changes in the potassium concentration of the plasma were very irregular.

TABLE 13

SODIUM, CHLORIDE AND POTASSIUM CONCENTRATIONS OF THE PLASMA BEFORE SAUNA AND IN SAUNA IN GROUP II

Test subjects received water and physiological saline solution.

Statistics	Sodium		Chloride		Potassium	
	Before Sauna	In Sauna	Before Sauna	In Sauna	Before Sauna	In Sauna
Mean .....mEq./l.	150	150	109	111	4.0	4.3
Range .... »	142—161	142—186	99—117	98—122	3.6—4.8	4.0—5.1
Mean change »	.	0	.	+2	.	+0.3
Standard error of mean change .... »	.	3	.	1	.	0.1
t	.	0.07	.	1.77	.	3.80
P	.	..	.	..	.	0.01

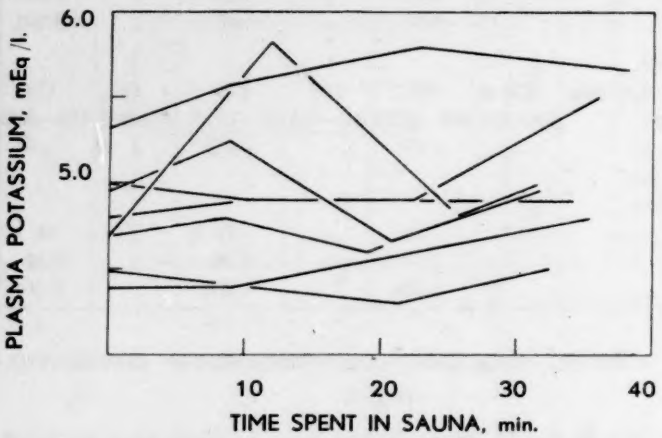

Fig. 12. — Graph showing variations in the potassium concentration of the plasma in the sauna in 8 of the test subjects who were not given water or salt (group III). The changes followed no consistent course.

RENAL CLEARANCE TESTS

In group I the glomerular filtration rate was determined by means of the single injection technique. The filtration rate averaged 115 ml./min. before the sauna bath. As is seen in table 14, no significant changes occurred in the sauna. In group II, in which the continuous infusion technique was used and the number of test subjects was larger, the mean rate before the sauna was 118 ml./min. No significant changes occurred during the latent period and sweating period I, but during sweating period II the glomerular filtration rate declined significantly at the 5 per cent level (table 14 and fig. 13). During this period the mean rate was 95 ml./min. No significant difference was found in comparative calculations made between groups I and II.

TABLE 14

GLOMERULAR FILTRATION RATE BEFORE SAUNA AND IN SAUNA

Filtration rate was determined by the inulin clearance test, using the single injection technique in group I and the continuous infusion technique in group II. All changes in the sauna are calculated from the values before the sauna

Statistics		Before Sauna	In Sauna		
			Latent Period	Sweating Periods	
				I	II
Group I					
Mean	ml./min.	115	115	104	91
Range	»	97—141	106—125	82—141	28—116
Mean change	»	.	0	—11	—22
Standard error of mean change	»	.	7	12	19
t		.	0.03	0.97	1.19
P		.	..	..	..
Group II					
Mean	ml./min.	118	122	105	95
Range	»	81—164	63—247	73—184	47—159
Mean change	»	.	+4	—13	—23
Standard error of mean change	»	.	9	9	9
t		.	0.47	1.41	2.52
P		.	..	..	0.05
Comparison of Groups I and II					
Difference of mean changes	ml./min.	.	—4	—1	—1
Standard error of difference	»	.	12	15	21
t		.	0.37	0.10	0.03
P		.	..	..	..

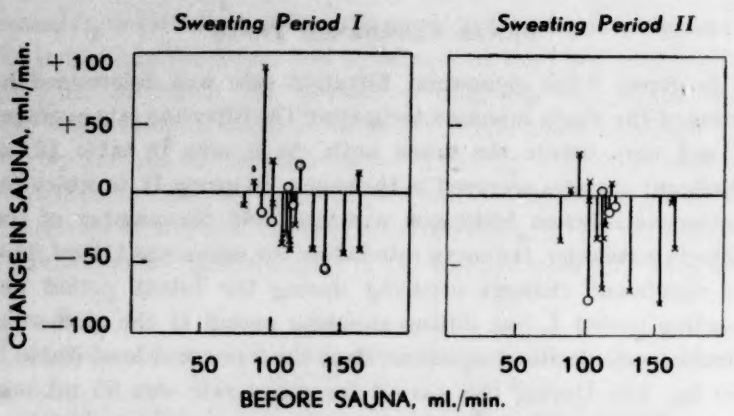

Fig. 13. — Graphs showing the glomerular filtration rate before the sauna and the changes occurring during two periods in the sauna. Comparisons in both periods are made with the pre-sauna rates. Changes during the latent period are not shown. No significant change occurred during period I. During period II the glomerular filtration rate decreased significantly.

O = Inulin clearance test using the single injection technique (group I)
× = Inulin clearance test using the continuous infusion technique (group II).

The renal plasma flow determined in group I by the single injection technique showed an average of 634 ml./min. before the sauna bath (table 15). The bath caused no significant change. In group II, using the continuous infusion technique, the mean renal plasma flow before the bath was 714 ml./min. No significant change occurred during the latent period, but during the sweating periods the renal plasma flow declined significantly at the 1 per cent level. During sweating period I the renal plasma flow averaged 578 ml./min. and during sweating period II 534 ml./min. (table 15 and fig. 14). A comparative calculation between groups I and II revealed no significant difference. As shown in table 16, the filtration fraction did not change significantly in the sauna in either group.

TABLE 15

RENAL PLASMA FLOW BEFORE SAUNA AND IN SAUNA

Renal plasma flow was determined by the PAH clearance test, using the single injection technique in group I and the continuous infusion technique in group II. All changes in the sauna are calculated from the values before the sauna.

Statistics		Before Sauna	In Sauna		
			Latent Period	Sweating Periods	
				I	II
Group I					
Mean	ml./min.	634	592	509	423
Range	»	419—810	351—823	351—764	285—693
Mean change	»	.	—42	—126	—236
Standard error of mean change	»	.	55	86	134
t		.	0.77	1.47	1.77
P		.	..	..	..
Group II					
Mean	ml./min.	714	710	578	534
Range	»	459—1092	277—1346	311—858	210—966
Mean change	»	.	—4	—136	—180
Standard error of mean change	»	.	62	37	44
t		.	0.07	3.66	4.12
P		.	..	0.01	0.01
Comparison of Groups I and II					
Difference of mean changes	ml./min.	.	—38	—10	—56
Standard error of difference	»	.	83	94	141
t		.	0.46	0.11	0.40
P		.	..	..	..

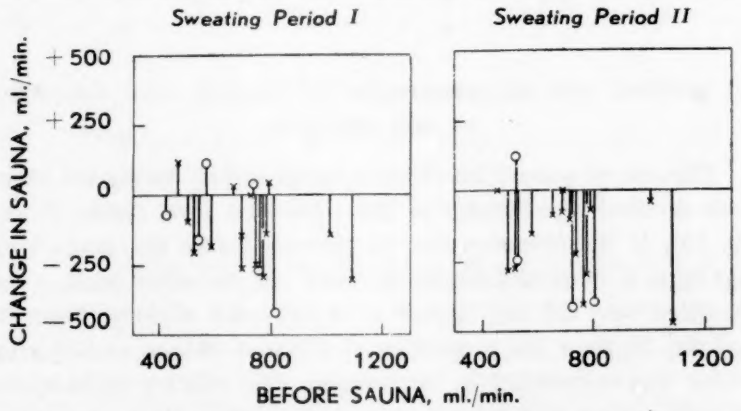

Fig. 14. — Graphs showing the renal plasma flow before the sauna and the changes occurring during two periods in the sauna. Comparisons in both periods are made with the pre-sauna rates. Changes during the latent period are not shown. The renal plasma flow decreased significantly during both sweating periods.

O = PAH clearance test using the single injection technique (group I).
× = PAH clearance test using the continuous infusion technique (group II).

TABLE 16

FILTRATION FRACTION BEFORE SAUNA AND IN SAUNA

Statistics		Before Sauna	In Sauna		
			Latent Period	Sweating Periods	
				I	II
Group I					
Mean	%	19	21	23	23
Range	»	14—23	13—30	11—37	9—40
Mean change	»	.	+2	+4	+5
Standard error of mean change	»	.	2	3	6
t		.	1.20	1.17	0.97
P		.	..	..	..
Group II					
Mean	%	17	18	20	18
Range	»	12—22	12—26	13—32	11—25
Mean change	»	.	+1	+3	+1
Standard error of mean change	»	.	1	1	1
t		.	1.31	1.88	1.89
P		.	..	..	..
Comparison of Groups I and II					
Difference of mean changes	%	.	1	1	4
Standard error of difference	»	.	2	4	6
t		.	0.50	0.36	0.73
P		.	..	..	..

FILTRATION AND REABSORPTION OF SODIUM AND CHLORIDE IN THE KIDNEYS

The rate of sodium filtration in the glomeruli during the sauna bath declined significantly at the 1 per cent level (table 17 and fig. 15). If the filtration rate of chloride before the sauna bath was high, it decreased during the bath. On the other hand, a low filtration rate did not change or it increased slightly. Table 18 and fig. 16 show the proportion of filtrated sodium and chloride which was reabsorbed in the tubules. The relative reabsorption of both sodium and chloride increased significantly in the sauna.

TABLE 17

SODIUM AND CHLORIDE FILTRATION RATES IN THE GLOMERULI BEFORE SAUNA AND IN SAUNA IN GROUP II

Statistics	Sodium		Chloride	
	Before Sauna	In Sauna	Before Sauna	In Sauna
Mean ..... mEq./min.	17.9	14.8	12.5	11.1
Range ..... »	12.0—24.7	10.2—25.2	9.0—18.3	8.0—19.7
Mean change .... »	.	—3.1	.	—1.4
Standard error of mean change .... »	.	1.0	.	1,1
t	.	3.08	.	1.27
P	.	0.01	.	..

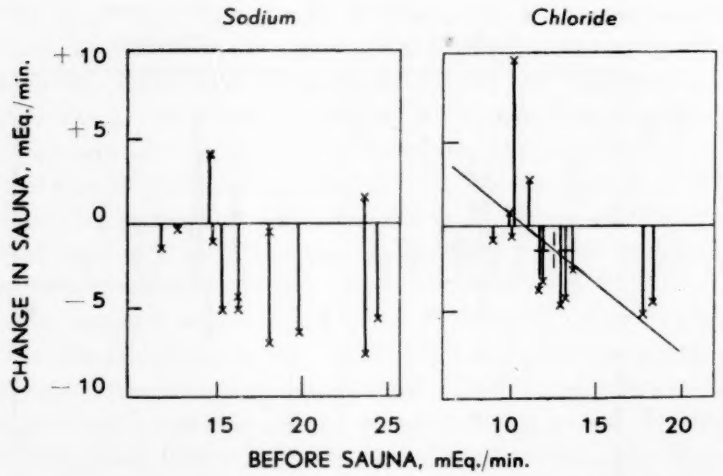

Fig. 15. — Graphs showing the sodium and chloride filtration rates in the glomeruli before the sauna and the changes occurring in the sauna in test persons receiving water and salt (group II), together with a regression line expressing the average relation for chloride filtration. The filtration rate of sodium was significantly lower in the sauna than before the sauna. If the filtration of chloride was high before the sauna it decreased, but a low chloride filtration rate increased but slightly or not at all. Equation of the regression line for the change in the chloride filtration rate in the sauna is $x_0 = 8.8—0.81\ x_1$.

TABLE 18

REABSORPTION OF SODIUM AND CHLORIDE BY THE TUBULES BEFORE SAUNA AND IN SAUNA IN GROUP II

Reabsorption of the electrolytes is expressed as percentages of the filtrated amounts.

Statistics		Sodium		Chloride	
		Before Sauna	In Sauna	Before Sauna	In Sauna
Mean	%	98.2	99.0	97.7	98.4
Range	»	96.8—99.5	97.6—99.9	96.1—99.5	96.1—99.7
Mean change	»	.	+0.8	.	+0.7
Standard error of mean change	»	.	0.2	.	0.3
t		.	3.41	.	2.66
P		.	0.01	.	0.05

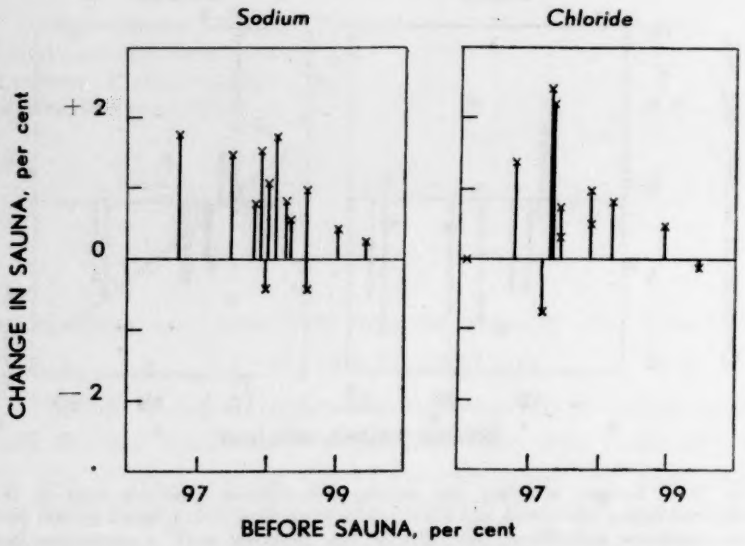

Fig. 16. — Graphs showing the reabsorption of sodium and chloride by the tubules before the sauna and the changes occurring in the sauna in test persons receiving water and salt (group II). Reabsorption is expressed as percentage of the filtrated amount. A significant increase was seen in the reabsorption of both sodium and chloride in the sauna.

DISCUSSION

Amount of Sweat in the Sauna. — Newburgh and Johnston (1942) studied the insensible perspiration at room temperature and found the rate to be 25—33 ml. per hour. At the beginning of the sauna bath, before sweating takes place and while the skin still is cold, there probably occurs no loss of fluid but to some small degree there is condensation of water vapour on the skin (Lundgren 1933). It is naturally difficult to obtain any definite information concerning the insensible perspiration during sweating. However, taking into consideration the slightness of the phenomenon in comparison to sweating, it is presumably of no notable significance under sauna bath conditions. According to Brofeldt (1942), no loss of water occurs by way of respiration in the sauna, since the absolute amount of humidity in the sauna atmosphere is sufficiently great to saturate with water vapour the inhaled air as it cools in the respiratory passages.

The weight loss may therefore be regarded as a good indicator of the amount of sweat. There were great individual variations in the weight loss during the sauna bath. The mean weight loss was of the same magnitude as the largest losses reported in earlier investigations, which were 900 gm. (Eisalo 1956) and 700 gm. (Räsänen 1951).

Sodium, Chloride and Potassium Concentrations of Sweat in the Sauna. — The sweat sodium, chloride and potassium concentrations were determined from the general body sweat. To calculate the concentrations of the electrolytes the amounts of sodium, chloride and potassium in the total body sweat were divided by the weight loss. This method is recommended, among others, by Kuno (1956), as the evaporation of water from the sweat does not cause an error in the concentrations of the examined non-

evaporating substances in the sweat. This method also does not alter the temperature or humidity of the ambient air, and it furthermore makes it possible to determine the total loss of the examined substances in the sweat. Because of insensible perspiration, desquamation, secretion of sebum and other factors the sweat sample obtained from the body surface does not fully conform in composition to the secretion of the sweat glands. The sodium, chloride and potassium concentrations of sweat varied greatly with the different test subjects. In group III, in which the subjects received no water or saline solution and spent the usual length of time in the sauna, the sodium concentration of the sweat varied from 13 to 70 mEq./l., the chloride concentration from 14 to 60 mEq./l. and the potassium concentration from 2.0 to 14.8 mEq./l. The variations over such a wide range are probably attributable to the numerous factors which influence the mineral composition of sweat, as has been described in the section »Sodium, Chloride and Potassium Concentrations of Sweat» (page 13). In earlier investigations (table 2, page 16) the analyses were made of the sweat collected in the sauna into a plastic bag enclosing an upper extremity. The individual variations were great also in these studies. The mean sodium, chloride and potassium concentrations obtained by the method employed by the present writer were lower than those obtained by the earlier investigators. This accords with the finding of some investigators working in other hot environments (cf. page 14) that the sweat collected into an impermeable bag enclosing an upper extremity is more concentrated than freely excreted general body sweat.

Sodium, Chloride and Potassium Losses in Sweat in the Sauna. — It was estimated by von Knorre (1943) that 1—2 gm. of sodium chloride is lost in the sweat during an ordinary sauna bath. In the writer's experiments the smallest loss of sodium chloride was 0.3 gm. and the greatest loss 3.8 gm. The greater the amount of sweat secreted in the sauna, the higher the sodium, chloride and potassium loss in the sweat. Böttner and Schlegel (1940) made a similar observation concerning the chloride loss in other hot environments.

Diuresis and Urine Electrolytes in Ambient Heat. — Diuresis was found to be reduced under the ordinary sauna conditions, as observed also in earlier experiments reported in the literature. The greatest and most consistent change was observable in the

excretion rate of sodium. A significant decrease was seen already during the latent period in the sauna. The urinary excretion rate of chloride also declined in the sauna, but the decrease did not occur as soon and was not as great. In general a good conformity was found between the excretion rates of sodium and chloride. On the other hand, the excretion pattern of potassium was different. Where the potassium excretion rate had been low before the sauna bath it increased in the sauna, and if it previously had been high it declined. To the writer's knowledge, the effect of the sauna bath on the urinary excretion of electrolytes has not been studied previously. In certain other hot environments the urinary sodium and chloride excretion rates were found to decrease, but no consistent change was found in the excretion of potassium (cf. page 17). Weiner (1947) found that the lower excretion of sodium chloride was not a result of reduced diuresis and that it was demonstrable also when the water and salt losses were fully compensated. The results obtained during the sauna bath by the present writer are in conformity with Weiner's findings. The urinary excretion rate of sodium and chloride decreased in the sauna both in the group which was given no fluids and in that which received water perorally and physiological saline parenterally throughout the experiment. Gruzdev (1889) observed a decrease in the urine chloride concentration in a hot steam bath. In the writer's series, on the other hand, the urine chloride concentration did not change significantly during the sauna bath. Bass *et al.* (1955) observed a decline in the sodium/potassium ratio in a hot environment. The results of the present investigation made in the Finnish sauna are in agreement with this finding.

Renal Filtration and Reabsorption of Sodium and Chloride in Ambient Heat. — The reduced excretion of sodium in the urine during the sauna bath was, according to the calculations, a result of both a decreased filtration rate of sodium in the glomeruli and an increased reabsorption by the tubules. On the other hand, the fall in the urine chloride in the sauna was probably due only to its increased reabsorption by the tubules. The effect of heat on the renal salt excretion mechanism has earlier been studied among others by Baráth (1954). According to his experiments the chloride clearance is reduced in a hot environment but its reabsorption remains unchanged. The results obtained by the present writer

conform with Baráth's findings in the respect that the chloride excretion rate in the sauna decreased, but conflict with them in that the reabsorption of chloride increased.

Effect of the Sauna Bath on the Total Loss of Sodium, Chloride and Potassium. — Arn and Reimer (1950) studied the loss of sodium, chloride and potassium from the skin of two test subjects under experimental conditions in which they did not sweat. Under these conditions the loss of these salts was very low. During 24 hours the losses were only 4.06—4.40 mEq. of sodium, 3.24—3.82 mEq. of chloride and 3.0—5.7 mEq. of potassium. Since the amounts are so low, the sodium, chloride and potassium losses through the skin before the sauna bath were not determined in the present investigation. The amounts lost in the urine were therefore regarded as the total loss before the bath, and the losses in urine and sweat were considered to be the total loss in the sauna. The total loss of these electrolytes increased 2- to 7-fold in the sauna. Although less sodium and chloride were lost in the urine in the sauna than at ordinary room temperature, the decrease was not sufficient to compensate their great loss in the sweat.

Plasma Sodium, Chloride and Potassium Concentrations in the Sauna. — Since this investigation was not concerned with the transfer of water and electrolytes within the organism, i.e., between the intracellular fluid, interstitial fluid and plasma, it is not possible to discuss the factors which influence the changes in plasma sodium, chloride and potassium concentrations. In the sauna the sodium and chloride concentrations of the plasma showed irregular variations. On the other hand, Karvonen, Friberg and Anttila (1955) observed an increase in the plasma chloride concentration in the sauna. The plasma potassium increased significantly during a prolonged stay in the sauna. However, when the changes in the plasma potassium concentration were followed by means of blood samples taken at intervals of 10 minutes, very irregular changes only were observed.

Secretion of Antidiuretic Hormone in the Sauna. — Karvonen, Friberg and Anttila (1955) regarded it as probable that the release of antidiuretic hormone from the posterior pituitary is stimulated in the sauna. This hormone, which has the effect of increasing the reabsorption of water by the renal tubules, does not produce any definite change in the electrolyte excretion in humans when admin-

istered in physiological doses (Chalmers, Lewis and Pawan 1951, Holland and Stead 1951, White, Rubin and Leiter 1951, Murphy and Stead 1951, Leaf *et al.* 1953). Murphy and Stead found that the antidiuretic hormone had no effect on the glomerular filtration rate or the renal plasma flow.

Is the Secretion of Adrenal Mineralocorticoids Increased in the Sauna? — The sodium and chloride excretion rates in the urine were found to decrease during the sauna bath but the excretion rate of potassium showed an increase in some cases and a decrease in others. The urinary potassium/sodium ratio increased in the sauna. An increase occurred in the reabsorption of sodium and chloride by the tubules during the bath. Changes of this kind may be ascribed to a number of factors, the best known of which is stimulation of adrenocortical function. The secretion of mineralocorticoids has not been studied under sauna conditions. Collins *et al.* (1955), Falbriard *et al.* (1955) and Streeten *et al.* (1955) found that heat increased the secretion of aldosterone, one of these mineralocorticoids. For this reason it seems probable that the changes produced by the sauna bath in the rates of sodium, chloride and potassium excretion in the urine may at least in part be due to an increased secretion of mineralocorticoids.

Comments on the Renal Clearance Tests Used. — The preliminary studies on the effect of the sauna bath on renal clearances (group I) were carried out by the single injection technique, the test subject voiding the urine spontaneously. Thus the conditions did not greatly differ from those existing during an ordinary sauna bath. There may also be reason to assume that the psychic stress in this group was not as great as in the group in which the clearance tests were carried out by the continuous infusion technique. Goldring *et al.* (1940), Wolf (1943) and Pfeiffer and Wolff (1950) have observed in clearance tests that psychic factors have a decreasing effect on the glomerular filtration rate and the renal plasma flow. In animal experiments using the thermo-stromuhr the renal blood flow has been found to decrease when the kidney sympathetics are stimulated (Burton-Opitz and Lucas 1908, Averbeck, Meitner and Schneider 1942). As was pointed out on page 25, a number of sources of error are present in the single injection technique, especially if it is used for comparison of the effects of different conditions. If the bladder cannot be completely emptied on spontaneous

micturition, merely the reduced diuresis may give rise to a systematic error manifesting as a reduction in the renal clearances. Since earlier investigations (cf. page 17) showed that diuresis decreased in the sauna, the greater proportion of the clearance tests (group II) were done by the continuous infusion technique. The urine samples were collected through an indwelling catheter and the bladder was rinsed with distilled sterile water at the end of each test period.

Glomerular Filtration Rate in the Sauna. — The glomerular filtration rate was determined by means of the inulin clearance test using the single injection and continuous infusion techniques. The mean glomerular filtration rate before the sauna bath was 115 ml./min. by the former and 118 ml./min. by the latter technique. These means were of the same magnitude as those previously reported in the literature. Smith (1951) collected from the literature the inulin clearance values obtained by the continuous infusion technique and reported the weighted mean of healthy men to be 127 ml./min., the clearances being corrected to 1.73 sq.m. body surface area. The glomerular filtration rate in the present investigation did not change significantly during a sauna bath of the usual duration. Less than ½ hour, i.e., sweating period I, was considered to be the time usually spent in a Finnish sauna bath. Only after a longer stay in the sauna, over ½ hour, the glomerular filtration rate declined significantly in the group studied by the continuous infusion technique. During the latter period, sweating period II, the mean glomerular filtration rate was 95 ml./min.

Renal Plasma Flow in the Sauna. — The renal plasma flow was determined by the PAH clearance, using both single injection and continuous infusion techniques. By the former technique the mean renal plasma flow before the sauna bath was 634 ml./min. and by the latter technique 714 ml./min. The values were of the same magnitude as those obtained by earlier investigators, i.e., 628 ml./min. (Brun, Hilden and Raaschou 1947) and 654 ml./min. (Smith 1951) corrected to 1.73 sq.m. body surface area. The renal plasma flow decreased in the sauna, and in the continuous infusion group averaged 578 ml./min. during sweating period I and 534 ml./min. during sweating period II. Compared with the value obtained before the sauna, the decrease was significant. Theoretically the decline in the PAH clearance may be caused either by reduced PAH extraction ratio or by decreased renal plasma flow.

No studies have been made of PAH extraction ratio in hot environments. It is, however, constant in man under physiological conditions of the most varied kinds (Cargill 1948, Reubi and Schroeder 1949, Werkö, Bucht and Josephson 1949, Bucht 1951). For this reason the decrease in the PAH clearance in the sauna must probably be regarded as the result of a decreased renal plasma flow. The PAH clearances were determined when the concentration in the plasma was in the range of 1—4 mg. per 100 ml., the extraction ratio then being maximal. In experiments with dogs it has been found that blood pressure variations in the renal artery in the range 150—100 mm. Hg (Selkurt, Hall and Spencer 1949), 184—88 mm. Hg (Selkurt 1951) or 180—80 mm. Hg (Shipley and Study 1951) produce no change in the glomerular filtration rate or the renal blood flow. For this reason it may be considered probable that the relatively small changes in the blood pressure which occur in the sauna (Lundgren 1933, Bardenheuer 1943, von Knorre 1943, Ott 1948, Eggers and Goll 1952, Luder 1954, Eisalo 1956) have no effect on the kidney haemodynamics.

Effect of Environmental Heat on Renal Clearances. — Byfield, Telser and Keeton (1943) found that mild heat has no effect on the glomerular filtration rate and causes a slight decrease in the renal plasma flow in a few cases only. Radigan and Robinson (1949) and Smith, Robinson and Pearcy (1952) carried out their renal clearance tests at different temperatures on different days. This makes the evaluation of the results difficult, since clearance values vary somewhat from day to day (Davies and Shock 1950). Radigan and Robinson found that both the glomerular filtration rate and the renal plasma flow declined in a hot environment. On the other hand, Smith, Robinson and Pearcy found no change in them unless the heat caused dehydration of a relatively high degree. Kenney (1952) and Baráth (1954) observed a decrease in the glomerular filtration rate and the renal plasma flow due to heat. Although the results of the earlier investigations disagree to some extent, most investigators are of the opinion that a high ambient heat has a lowering effect on the glomerular filtration rate and the renal plasma flow. The results obtained in the sauna in the present investigation are in agreement with this opinion provided the subject spends a sufficient length of time in the hot environment. If, on the other hand, only the usual length of time is spent in the sauna (less than ½

hour) a decrease is seen in the renal plasma flow only, and no definite change is evident in the glomerular filtration rate.

Renal Fraction in the Sauna. — The renal fraction is that portion of the cardiac output which passes through the kidneys. Eisalo (1956) found that the cardiac output increases considerably in the sauna. In the present investigation, on the other hand, the renal plasma flow decreased during the sauna bath. According to Eisalo no notable change occurred in the haematocrit value. On this basis the decrease in the renal plasma flow may also be regarded as an indication of a decrease in the renal blood flow. It therefore seems probable that the renal fraction decreases in the sauna very considerably. On the other hand, the blood circulation in the extremities increases according to Lundgren (1933), who measured the circulation in the forearm with a plethysmograph. However, it decreased for a short time every time steam was produced by throwing water on the hot stones on the furnace. These observations on the effect of the sauna bath conform well with the results obtained by Redisch *et al.* (1954) in his investigations. While their test subjects held one extremity in a hot (44°—45°C) water bath, the blood circulation in the other extremities was measured with a plethysmograph and the renal blood flow by the PAH clearance test. An increase in the circulation in the extremities and a decrease in the circulation in the kidneys were observed to occur nearly simultaneously.

Diurnal Variations in Renal Function. — The changes observed in renal function during the sauna bath cannot be diurnal variations. The inulin and PAH clearances, the diuresis (Sirota, Baldwin and Villarreal 1950) and the sodium, chloride and potassium excretion rates (Norn 1929, Stanbury and Thomson 1951) are lower during the night than during the day. The experiments in the present investigation were carried out during the forenoon and midday, when the renal clearances and the excretion rates of water and of the above mentioned electrolytes have an increasing trend. Nevertheless a decrease was observed in the excretion rates of water, sodium and chloride and in the PAH clearance during the usual sauna bath, and a decrease also in the inulin clearance during a longer bath.

SUMMARY

The object of this investigation was to study the effect of the Finnish sauna bath on the excretion rates of sodium, chloride and potassium in the sweat and the urine and on the renal clearances.

The series of test subjects consisted of 40 healthy males, who were distributed into three groups. In group I the renal clearance tests only were made, while in group II the renal clearance tests and the electrolyte excretion studies and in group III only the electrolyte excretion studies were performed. The effect of the sauna bath on the following factors was determined: Amounts of sweat and urine; sodium, chloride and potassium concentrations of sweat and urine (mEq./l.); loss of these electrolytes in sweat (mEq.) and in urine (μEq./min.); total losses of these electrolytes; rates of sodium and chloride filtration and reabsorption in the kidneys; plasma sodium, chloride and potassium concentrations (mEq./l.); glomerular filtration rate (inulin clearance test) and renal plasma flow (PAH clearance test).

The amount of sweat was determined as the body weight loss. It varied in the range of 100—2,000 gm. and averaged 740 gm. The electrolytes in the sweat were determined from the general body sweat. The loss of sodium chloride in sweat varied between 0.3 and 3.8 gm. Marked individual differences were seen in the sodium, chloride and potassium concentrations of the sweat. The mean sodium concentration was 39 mEq./l., chloride concentration 32 mEq./l. and potassium concentration 4.7 mEq./l.

Diuresis decreased in the sauna. The sodium concentration of the urine decreased, the chloride concentration was unchanged, and the potassium concentration increased in persons who received no fluids during the experiment. The urinary potassium/sodium ratio increased greatly. Of all the factors studied, the urinary excretion rate of sodium appears to have been influenced the most

by the sauna bath, since it decreased markedly. According to calculations made, the reason for the decreased urinary excretion of sodium was both a decline in the rate of sodium filtration in the glomeruli and an increase in the reabsorption by the tubules. The rate of chloride excretion in the urine also declined during the sauna bath, although the change was not as great or as rapid as that seen in the sodium excretion rate. The filtration rate of chloride in the glomeruli in the sauna showed individual variations in both directions. The reabsorption of chloride in the sauna was greater than before the sauna bath. In cases in which the rate of urinary potassium excretion was low before the bath it increased in the sauna, and where it previously was high it decreased. A number of these changes in the excretion rates of electrolytes in the sauna resemble those produced by adrenal mineralocorticoids.

As a result of sweating, the total losses of sodium, chloride and potassium in the sauna were considerably greater than before the sauna. The retention of sodium and chloride in the kidneys was not adequate to compensate their substantial loss in sweat. In the plasma sodium, chloride and potassium concentrations no definite and consistent changes were observed during the sauna bath.

The glomerular filtration rate did not undergo any change during a sauna bath of the usual length, and a decrease was evident only during a protracted stay in the sauna. On the other hand, the renal plasma flow decreased clearly during a Finnish sauna bath of the usual length.

ZUSAMMENFASSUNG

Die Untersuchung hatte den Zweck, den Einfluss des finnischen Saunabades auf die Nierenclearance sowie auf die Ausscheidung von Natrium, Chlorid und Kalium im Harn und im Schweiss zu untersuchen.

Das Untersuchungsmaterial bildeten 40 gesunde Männer, die in drei Gruppen eingeteilt wurden. In der ersten Gruppe wurden ausschliesslich Clearance-Untersuchung vorgenommen, in der zweiten gleichzeitig die Clearance-Bestimmungen und die Untersuchungen über die Elektrolytenausscheidung sowie in der dritten nur die Elektrolytenuntersuchungen. Die Wirkung des Saunabades auf folgende Faktoren wurde untersucht: Schweiss- und Harnmenge; Natrium-, Chlorid- und Kaliumgehalt in Schweiss und Harn (mEq./L); Natrium-, Chlorid- und Kaliumverlust im Schweiss (mEq.) und im Harn (μ Eq./Min.); der Totalverlust dieser Elektrolyten; die Filtrations- und Reabsorptionsmengen von Natrium und Chlorid in den Nieren; Natrium-, Chlorid- und Kaliumgehalt des Plasmas; Glomerulusfiltration (Inulin-clearance) sowie Plasmazirkulation der Nieren (PAH-Clearance).

Die Schweissmenge wurde als Gewichtsverlust bestimmt. Derselbe variierte zwischen 100 und 2000 g und war durchschnittlich 740 g. Für die Untersuchung der Mineralien des Schweisses wurde in der Sauna die gesamte abgesonderte Schweissmenge gesammelt. Die mit dem Schweiss ausgeschiedene Kochsalzmenge variierte zwischen 0,3 und 3,8 g. Der Natrium-, Chlorid- und Kaliumgehalt im Schweiss wies grosse individuelle Unterschiede auf. Durchschnittlich war der Natriumgehalt 39 mEq./L, der Chloridgehalt 32 mEq./L und der Kaliumgehalt 4,7 mEq./L.

Die Harnmenge nahm in der Sauna ab. Der Natriumgehalt des Harns sank ab, der Chloridgehalt blieb unverändert, während der Kaliumgehalt bei Personen, die während des Versuchs nichts

zu trinken bekommen hatten, gleichzeitig zunahm. Das K/Na-Verhältnis stieg in der Sauna stark an. Von allen untersuchten Faktoren wurde durch das Saunabad vielleicht am kräftigsten die Natriumausscheidung im Harn beeinflusst, welche sehr viel abnahm. Die Ursache für die Abnahme der Natriumausscheidung im Harn war den Berechnungen gemäss einerseits eine Verminderung der in den Glomeruli filtrierten Natriummenge und andererseits eine Zunahme der in den Tubuli resorbierten Natriummenge. Auch die Chloridexkretion im Harn ging während des Saunabades zurück, obwohl die Veränderung nicht so kräftig und nicht so rasch eintrat wie die Abnahme der Natriumausscheidung. Die in den Glomeruli filtrierte Chloridmenge variierte im Saunabad individuell erheblich. Dahingegen war die Resorption von Chlorid während des Saunabads regelmässig grösser als vorher. Wenn die Kaliumexkretion im Harn vor dem Bad gering war, nahm sie in der Sauna zu, und umgekehrt nahm sie ab, wenn sie vor dem Bad gross gewesen war. Viele Veränderungen der Elektrolytenausscheidung im Saunabad sind ganz ähnlich wie die von den Mineralokortikoiden der Nebennieren hervorgerufenen Veränderungen.

Infolge der reichlichen Schweissabsonderung war der Gesamtverlust von Natrium, Chlorid und Kalium im Saunabad bedeutend grösser als vorher. Auch die Retention von Natrium und Chlorid in den Nieren reichte nicht aus, um deren grossen Verlust im Schweiss zu kompensieren. Im Natrium-, Chlorid- und Kaliumgehalt des Plasmas konnte während des Bads keine einheitliche, sichere Veränderung wahrgenommen werden.

Die Glomerulusfiltration war in der Sauna ziemlich stabil. Während eines Bades von gewöhnlicher Dauer veränderte sie sich überhaupt nicht. Erst bei aussergewöhnlich langem Aufenthalt in der Sauna liess sich eine Verminderung der Glomerulusfiltration beobachten. Die Plasmazirkulation in den Nieren dagegen nahm deutlich während des üblichen finnischen Saunabades ab.

BIBLIOGRAPHY

ADOLPH, E. F.: Initiation of Sweating in Response to Heat. — Amer. J. Physiol. 1946:*145:*710.

ADOLPH, E. F.: Physiology of Man in the Desert. — Interscience, New York, London, 1947.

AHLMAN, K. L., ERÄNKÖ, O., KARVONEN, M. J., and LEPPÄNEN, V.: Effects of Hard Competitive Muscular Work on Electrolyte Content of Thermal Sweat. — J. appl. Physiol. 1952:*4:*911.

AHLMAN, K. L., ERÄNKÖ, O., KARVONEN, M. J., and LEPPÄNEN, V.: Effects of Prehydration and Repeated or Prolonged Thermal Stress on the Electrolyte Content of Thermal Sweat. — Acta endocr. (Kbh.) 1953:*12:*140. (a).

AHLMAN, K. L., ERÄNKÖ, O., KARVONEN, M. J., and LEPPÄNEN, V.: Mineral Composition of Thermal Sweat in Healthy Persons. — J. clin. Endocr. 1953:*13:*773. (b).

ALVING, A. S., and MILLER, B. F.: A Practical Method for the Measurement of Glomerular Filtration Rate (Inulin Clearance). — Arch. intern. Med. 1940:*66:*306.

ARN, K. D., and REIMER, A.: Minimal Sodium Losses through the Skin. — J. clin. Invest. 1950:*29:*1342.

AVERBECK, G., MEITNER, H. J., and SCHNEIDER, M.: Über die nervöse Beeinflussung der Nierendurchblutung und der Harnausscheidung. — Z. ges. exp. Med. 1942:*111:*436.

BARÁTH, G.: Untersuchungen über die Nierenfunktion nach sportlichen Übungen und nach Einwirkung von trockener Wärme. — Arbeitsphysiologie 1954:*15:*383.

BARDENHEUER, F. H.: Anzeigestellung und Wirkung des Sauna-bades. — Med. Welt 1943:*17:*433.

BARTELS, K. W.: Zur physikalischen Grundlage und praktischen Anwendung des Saunabades. — Balneologe 1944:*11:*20.

BASS, D. E., KLEEMAN, C. R., and QUINN, M.: Human Acclimatization to Heat. — Boston Medical Quarterly 1953:*4:*97.

BASS, D. E., KLEEMAN, C. R., QUINN, M., HENSCHEL, A., and HEGNAUER, A.: Mechanisms of Acclimatization to Heat in Man. — Medicine (Baltimore) 1955:*34:*323.

BAZETT, H. C.: Theory of Reflex Controls to Explain Regulation of Body Temperature at Rest and during Exercise. — J. appl. Physiol. 1951:*4:* 245.

Bedford, T.: Environmental Warmth and its Measurement. — Med. Res. Council War Memo. No. 17, H. M. Stationery Office, London, 1946.

Berenson, G. S., and Burch, G. E.: Study of the Sodium, Potassium and Chloride Contents of Thermal Sweat of Man Collected from Small Isolated Areas of Skin. — J. Lab. clin. Med. 1953:*42:*58.

Berliner, R. W., and Kennedy, T. J., Jr.: Renal Tubular Secretion of Potassium in the Normal Dog. — Proc. Soc. exp. Biol. (N.Y.) 1948:*67:* 542.

Berliner, R. W., Kennedy, T. J., Jr., and Hilton, J. G.: Renal Mechanisms for Excretion of Potassium. — Amer. J. Physiol. 1950:*162:*348.

Berliner, R. W., Kennedy, T. J., Jr., and Orloff, J.: Relationship between Acidification of the Urine and Potassium Metabolism. — Amer. J. Med. 1951:*11:*274.

Black, D. A. K.: Sodium Metabolism in Health and Disease. — Blackwell Scientific Publ., Oxford, 1952.

Black, D. A. K., and Emery, E. W.: Tubular Secretion of Potassium. — Brit. med. Bull. 1957:*13:*7.

Blockley, W. V., MacCutchan, J. W., Lyman, J., and Taylor, C. L.: Human Tolerance for High Temperature Aircraft Environments. — J. Aviat. Med. 1954:*25:*515.

Bojesen, E.: The Function of the Urinary Tract as »Dead Space» in Clearance Experiments. — Scand. J. clin. Lab. Invest. 1949:*1:*290.

Böttner, H., and Schlegel, B.: Neue Untersuchungen über Kochsalz- und Stickstoffverluste durch die Haut. — Z. ges. Med. 1940:*108:*151.

Bradley, S. E., Curry, J. J., and Bradley, G. P.: Renal Extraction of p-Aminohippurate in Normal Subjects and in Essential Hypertension and Chronic Diffuse Glomerulonephritis. — Fed. Proc. 1947:*6:*79.

Brofeldt, S.: Über die finnische Sauna und ihre Wirkung. — Dtsch. Ärzteblatt 1942:p. 330.

Brun, C.: Klorbestemmelse. En mikrometode. — Nord. Med. 1949:*42:*1774.

Brun, C., Hilden, T., and Raaschou, F.: Para-aminohippursyre. Et Middel til Bestemmelse af Nyrernes Plasmagennemströmning og af den maximale tubulaere Secretion. — Nord. Med. 1947:*34:*803.

Brun, C., Hilden, T., and Raaschou, F.: The Significance of the Difference in Systemic Arterial and Venous Plasma Concentrations in Renal Clearance Methods. — J. clin. Invest. 1949:*28:*144. (a).

Brun, C., Hilden, T., and Raaschou, F.: Examinations of the Delay-time of the Kidney. — Scand. J. clin. Lab. Invest. 1949:*1:*348. (b).

Brun, C., Knudsen, E. O. E., and Raaschou, F.: The Influence of Posture on the Kidney Function, II: Glomerular Dynamics in the Passive Erect Posture. — Acta med.scand. 1945:*122:*332.

Bucht, H.: Examination of the Renal Plasma Flow by Means of Para-amino-hippuric Acid (PAH) Using One Intramuscular Injection. — Scand. J. clin. Lab. Invest. 1949:*1:*126.

Bucht, H.: Studies on Renal Function in Man. — Scand. J. clin. Lab. Invest. 1951:*3:*Suppl. 3.

Burch, G. E.: Environmental Conditions which Initiate Sweating in Resting Man. — Proc. Soc. exp. Biol. (N.Y.) 1948:*67:*521.

Burch, G. E., and Sodeman, W. A.: Regional Relationships of Rate of Water Loss in Normal Adults in a Subtropical Climate. — Amer. J. Physiol. 1943:*138:*603.

Burch, G. E., and Winsor, T.: Rate of Insensible Perspiration (Diffusion of Water) Locally through Living and through Dead Human Skin. — Arch. intern. Med. 1944:*74:*437. (a).

Burch, G. E., and Winsor, T.: Diffusion of Water through Living and Dead Human Skin with the Identification of the Diffusion Inhibiting Layer. — J. clin. Invest. 1944:*23:*937. (b).

Burton-Opitz, R., and Lucas, D. R.: Über die Blutversorgung der Nieren. — Pflügers Arch. ges. Physiol. 1908:*123:*553.

Byfield, G. V., Telser, S. E., and Keeton, R. W.: Blood Flow and Glomerular Filtration as Influenced by Environmental Temperature Changes. — J. Amer. med. Ass. 1943:*121:*118.

Cargill, W. H.: Effect of the Intravenous Administration of Human Serum Albumin on Renal Function. — Proc. Soc. Exp. Biol. (N.Y.) 1948:*68:*189.

Chalmers, T. M., Lewis, A. A. G., and Pawan, G. L. S.: The Effect of Posterior Pituitary Extracts on the Renal Excretion of Sodium and Chloride in Man. — J. Physiol. (Lond.) 1951:*112:*238.

Chasis, H., Redish, J., Goldring, W., Ranges, H., and Smith, H.: The Use of Sodium p-Amino-hippurate for the Functional Evaluation of the Human Kidney. — J. clin. Invest. 1945:*24:*583.

Collins, K. J., Hellman, K., Jones, R. M., and Lunnon, J. B.: Aldosteron Activity in the Urine of Men Exposed to Hot Environments. — J. Endocr. 1955:*13:*VIII.

Conley, C. L., and Nickerson, J. L.: Effects of Temperature Change on the Water Balance in Man. — Amer. J. Physiol. 1945:*143:*373.

Conn, J. W.: The Mechanism of Acclimatization to Heat. — Advanc. intern. Med. 1949:*3:*373. (a).

Conn, J. W.: Electrolyte Composition of Sweat. — Arch. intern. Med. 1949:*83:*416. (b).

Conn, J. W., Johnston, M. W., and Louis, L. H.: Acclimatization to Humid Heat: A Function of Adrenal Cortical Activity. — J. clin. Invest. 1946:*25:*912.

Conn, J. W., and Louis, L. H.: Production of Endogenous »Salt-active» Corticoids as Reflected in Concentrations of Sodium and Chloride of Thermal Sweat. — J. clin. Endocr. 1950:*10:*12.

Conn, J. W., Louis, L. H., Johnston, M. W., and Johnson, B. J.: The Electrolyte Content of Thermal Sweat as an Index of Adrenal Cortical Function. — J. clin. Invest. 1948:*27:*529.

Co-Tui, McCloskey, K. L., Schrift, M., and Yates, A. L.: A New Method of Preparing Infusion Fluids. — J. Amer. med. Ass. 1937:*109:*250.

Cuthbertson, D. P., and Guthrie, W. S. W.: The Effect of Variations in

Protein and Salt Intake on the Nitrogen and Chloride Content of Sweat. — Biochem. J. 1934:*28:*1444.

Daly, C., and Dill, D. B.: Salt Economy in Humid Heat. — Amer. J. Physiol. 1937:*118:*285.

Davies, D. F., and Schock, N. W.: The Variability of Measurement of Inulin and Diodrast Tests of Kidney Function. — J. clin. Invest. 1950: *29:*491.

Dill, D. B., Hall, F. G., and Edwards, H. T.: Changes in Composition of Sweat during Acclimatization to Heat. — Amer. J. Physiol. 1938: *123:*412.

Dill, D. B., Jones, B. F., Edwards, H. T., and Oberg, S. A.: Salt Economy in Extreme Dry Heat. — J. biol. Chem. 1933:*100:*755.

Eggers, P., and Goll, W.: Die Wirkung des Saunabades auf Herz und Kreislauf. — Dtsch. med. Wschr. 1952:*77:*863.

Eggleton, M. G., and Habib, Y. A.: The Mode of Excretion of Creatinine and Inulin by the Kidney of the Cat. — J. Physiol. (Lond.) 1951:*112:* 191.

Eichna, L. W., Bean, W. B., Ashe, W. F., and Nelson, N.: Performance in Relation to Environmental Temperature. — Bull. Johns Hopk. Hosp. 1945:*76:*25.

Eisalo, A.: Effects of the Finnish Sauna on Circulation. — Annales Med. exp. Biol. Fenn. 1956:*34:*Suppl. 4.

Evans, B. M., Jones, N. C. H., Milne, M. D., and Steiner, S.: Electrolyte Excretion during Experimental Potassium Depletion in Man. — Clin. Sci. 1954:*13:*305.

Falbriard, A., Muller, A. F., Neher, R., and Mach, R. S.: Études des variations de l'aldostéronurie sous l'effet de surcharges en potassium et de déperditions rénales et extrarénales de sel et d'eau. — Schweiz. med. Wschr. 1955:*85:*1218.

Ferguson, M. H., Olbrich, O., Robson, J. S., and Stewart, C. P.: The Use of Inulin Clearance as a Measure of Glomerular Filtration. — Quart. J. exp. Physiol. 1950:*35:*251.

Fisher, R. A., and Yates, F.: Statistical Tables for Biological, Agricultural and Medical Research. — Oliver & Boyd, Edinburgh, London, 1953.

Fritzsche, W.: Die Sauna — ein zeitgemässes Mittel zur Erhaltung und Regeneration der Leistungsfähigkeit. — Die Gesundheitssicherung 1956: Heft 6: 43.

Fukuda: 1947. — Cited by Kuno in: Human Perspiration. — 1956.

Gagge, A. P.: Standard Operative Temperature, a Generalized Temperature Scale, Applicable to Direct and Partitional Calorimetry. — Amer. J. Physiol. 1940:*131:*93.

Gernant, B., Holmgren, H., Schmiterlöw, E., and Sjöstrand, T.: Medicinskt-fysiologiska synpunkter på bastubadet. — Nord.hyg. T. 1944:*25:*346.

Goldring, W., Chasis, H., Ranges, H. A., and Smith, H. W.: Relations of Effective Renal Blood Flow and Glomerular Filtration to Tubular Excretory Mass in Normal Man. — J. clin. Invest. 1940:*19:*739.

GRAYSON, J.: Reactions of the Peripheral Circulation to External Heat. — J. Physiol. (Lond.) 1949;*109:*53.

GRUZDEV, V. S.: 1889. — Cited by LUNDGREN in: Tutkimuksia suomalaisesta saunasta. — 1933.

GUKELBERGER, M.: Die Veränderungen der Nierenfunktion unter dem Einfluss des warmen Vollbades und der Kurzwellenbestrahlung der Nieren. — Helvet. med. Acta 1945:*12:*175.

HANCOCK, W., WHITEHOUSE, A. G. R., and HALDANE, J. S.: The Loss of Water and Salts through the Skin, and the Corresponding Physiological Adjustments. — Proc. roy. Soc. B 1929:*105:*43.

HASAN, J., LAAMANEN, A., and NIEMI, M.: Effect of Thermal Stress and Muscular Exercise, with and without Insulin Hypoglycaemia, on the Body Temperature, Perspiration Rate and Electrolyte and Lactate Content of Sweat. — Acta physiol. scand. 1954:*31:*131.

HELLMAN, K., GRAY, C. H., LUNNON, J. B., and WEINER, J. S.: The Excretion of Urinary Adrenocortical Steroids during Heat Stress. — J. Endocr. 1954:*10:*XVIII.

HELLMAN, K., and WEINER, J. S.: Antidiuretic Substance in Urine Following Exposure to High Temperatures. — J. app. Physiol. 1953: *6:*194.

HENDRIX, J. P., WESTFALL, B. B., and RICHARDS, A. N.: Quantitative Studies of the Composition of Glomerular Urine. — J. biol. Chem. 1936:*116:*735.

HENN, O.: Der Chloridgehalt des Schweisses bei hoher Temperatur, hoher relativer Feuchtigkeit, aber körperliche Ruhe. — Arbeitsphysiologie 1953:*15:*93.

HERMANSON, V., and HARTMAN, F. A.: Protection of Adrenalectomized Rats against High Temperature. — Amer. J. Physiol. 1945:*144:*108.

HERTZMAN, A. B.: The Individualistic Character of the Relation of Regional Sweating Rates to Total Weight Loss in Normal Subjects. — U. S. Air Force Techn. Rep. No. 6680, Part 15, 1954.

HERTZMAN, A. B., RANDALL, W. C., PEISS, C. N., and ADAMS, J. G.: Cutaneous Thermosensory Recruitment of Sweating. — U. S. Air Force Techn. Rep. No. 6680, Part 13, 1953.

HERTZMAN, A. B., RANDALL, W. C., PEISS, C. N., and SECKENDORF, R.: Regional Rates of Evaporation from the Skin at Various Environmental Temperatures. — J. appl. Physiol. 1952:*5:*153.

VAN HEYNINGEN, R., and WEINER, J. S.: A Comparison of Arm-bag Sweat and Body Sweat. — J. Physiol. (Lond.) 1952:*116:*395.

HILGERS, A.: Erfahrungen bei flammenphotometrischen Natrium-, Kalium- und Calcium-Bestimmungen im Blutserum. — Hoppe-Seyl. Z. physiol. Chem. 1953:*294:*61.

HOLLAND, B. C., and STEAD, E. A., JR.: Effect of Vasopressin (Pitressin)-induced Water Retention on Sodium Excretion. — Arch. intern. Med. 1951:*88:*571.

HOUGHTEN, F. C., and YAGLOGLOU, C. P.: 1923. — Cited by SMITH in: Indices of Heat Stress. — 1955.

Hubbard, R. S., and Loomis, T. A.: The Determination of Inulin. — J. biol. Chem. 1942:*145:*641.

Hunter, F. R.: Observations on the Use of the Flame Photometer for Analyses of Blood. — J. biol. Chem. 1951:*192:*701.

Itoh, S.: The Release of Antidiuretic Hormone from the Posterior Pituitary Body on Exposure to Heat. — Jap. J. Physiol. 1954:*4:*185.

Johnson, R. E., Pitts, G. C., and Consolazio, F. C.: Factors Influencing Chloride Concentration in Human Sweat. — Amer. J. Physiol. 1944: *141:*575.

Josephson, B., Bucht, H., Ek, J., and Werkö, L.: Renal Extraction, its Depression and the Tubular Storage of p-Aminohippuric Acid in the Healthy and in the Diseased Human Kidney. — Scand. J. clin. Lab. Invest. 1952:*4:*1.

Kalant, N.: Observations on the Use of Para-aminohippuric Acid (PAH) in Kidney Function Tests. — J. Lab. clin. Med. 1950:*35:*829.

Kanter, G. S.: Heat and Excretion in Man. — J. appl. Physiol. 1955:*7:* 533.

Karvonen, M. J., Friberg, O., and Anttila, E.: Urine Flow and Water Balance in the Sauna-bath. — Ann. Med. exp. Biol. Fenn. 1955:*33:*326.

Kawahata. 1951. — Cited by Kuno in: Human Perspiration. — 1956.

Kennedy, Th. J., Jr., and Kleh, J.: The Relationship between the Clearance and the Plasma Concentration of Inulin in Normal Man. — J. clin. Invest. 1953:*32:*90.

Kenney, R. A.: The Effect of Hot, Humid Environments on the Renal Function of West Africans. — J. Physiol. (Lond.) 1952:*118:*25 P.

Kittsteiner, C.: Sekretion, Kochsalzgehalt und Reaktion des Schweisses. — Arch. Hyg. (Berl.) 1911:*73:*275.

Kittsteiner, C.: Weitere Beiträge zur Physiologie der Schweissdrüsen und des Schweisses. — Arch. Hyg. (Berl.) 1913:*78:*275.

Kleinschmidt, A.: Zur Methodik exakter Clearance-Untersuchungen. — Ärztl. Wschr. 1953:*8:*1142.

Knorre, G. von: Über einige vegetative Regulationen im Saunabad. — Balneologe 1943:*10:*217.

Kuno, Y.: Human Perspiration. — Charles Thomas, Springfield, 1956.

Laake, H.: Inulin Clearance Studies Concerning the Causes of the Reduced Clearance Figures in Successive Periods after One Injection of Inulin. — Acta med. scand. 1954:*148:*135.

Ladell, W. S. S.: Changes in the Chloride Concentration of Sweat with Acclimatization. — Biochem. J. 1945:*39:*xlvii. (a).

Ladell, W. S. S.: Thermal Sweating. — Brit. med. Bulletin 1945:*3:*175. (b).

Ladell, W. S. S.: The Effect of Desoxycorticosterone Acetate on the Chloride Content of the Sweat. — J. Physiol. (Lond.) 1945:*104:*13 P. (c).

Ladell, W. S. S.: The Measurement of Chloride Losses in the Sweat. — J. Physiol. (Lond.) 1948:*107:*465.

Ladell, W. S. S., Waterlow, J. C., and Hudson, M. F.: Desert Climate. Physiological and Clinical Observations. — Lancet 1944:*II:*491.

Leaf, A., Bartter, F. C., Santos, R. F., and Wrong, O.: Evidence in Man that Urinary Electrolyte Loss Induced by Pitressin Is a Function of Water Retention. — J. clin. Invest. 1953:*32:*868.

Leaf, A., and Camara, A. A.: Renal Tubular Secretion of Potassium in Man. — J. clin. Invest. 1949:*28:*1526.

Lee, D. H. K., Murray, R. E., Simmonds, W. J., and Atherton, R. G.: Effect of Exercise in Hot Atmospheres upon Salt—Water Balance of Human Subjects. — Med. J. Australia 1941:*2:*249.

Lehmann, G., and Szakáll, A.: Weitere Untersuchungen über den Chlorumsatz bei Hitzearbeit. — Arbeitsphysiologie 1939:*10:*608.

Lehtmets, M. L.: The Sauna Bath: History, Development and Physiological Effects. — Amer. J. phys. Med. 1957:*36:*21.

Locke, W., Talbot, N. B., Jones, H. S., and Worcester, J.: Studies on the Combined Use of Measurements of Sweat Electrolyte Composition and Rate of Sweating as an Index of Adrenal Cortical Activity. — J. clin. Invest. 1951:*30:*325.

Luder, P.: Ein Versuch zur Beurteilung des Zusammenhangs der Thermoregulation gesunder männlicher Versuchspersonen in extremer Hitze und Kälte mit ihrer Nebennierentätigkeit. — Schweiz. Z. Sportmed. 1954:*2:*68.

Luetscher, J. A., Jr., and Curtis, R. H.: Aldosterone: Observations on the Regulation of Sodium and Potassium Balance. — Ann. intern. Med. 1955:*43:*658. (a).

Luetscher, J. A., Jr., and Curtis, R. H.: Observations on Aldosterone in Human Urine. — Fed. Proc. 1955:*14:*746. (b).

Luetscher, J. A., Jr., and Johnson, B. B.: Observations on the Sodium-retaining corticoid (Aldosterone) in the Urine of Children and Adults in Relation to Sodium Balance and Edema. — J. clin. Invest. 1954: *33:*1441.

Lundgren, R.: Tutkimuksia suomalaisesta saunasta (Studies on the Finnish Sauna Baths). — Kouvolan kirja- ja kivipaino Oy, Kouvola, 1933.

McArdle, B., Dunham, W., Holling, H. E., Ladell, W. S. S., Scott, J. W., Thomson, M. L., and Weiner, J. S.: 1947 — Cited by Smith in Indices of Heat Stress. — 1955.

McCance, R. A.: The Effect of Salt Deficiency in Man on the Volume of the Extracellular Fluids, and on the Composition of Sweat, Saliva, Gastric Juice and Cerebrospinal Fluid. — J. Physiol. (Lond.) 1938:*92:*208.

Mach, R. S., Fabre, J., Duckert, A., Borth, R., and Ducommun, P.: Action clinique et métabolique de l'Aldosterone (Electrocortine). — Schweiz. med. Wschr. 1954:*84:*407.

McSwiney, R. R., and de Wardener, H. E.: Renal-tract Delay Time and Dead Space. — Lancet 1950:*II:*845.

Martin, A. R.: 1765. — Cited by Lundgren in: Tutkimuksia suomalaisesta saunasta. — 1933.

Mickelsen, O., and Keys, A.: The Composition of Sweat with Special Reference to the Vitamins. — J. biol. Chem. 1943:*149:*479.

MIETTINEN, M., and ANTTILA, E.: Effect of the Finnish Steam Bath and Bathing in Ice-cold Water on the Mineral Content of the Sweat. — Acta endocr. (Kbh.) 1955:*20:*157.

MILLER, B. F., ALVING, A. S., and RUBIN, J.: The Renal Excretion of Inulin at Low Plasma Concentrations of This Compound and its Relationship to the Glomerular Filtration Rate in Normal, Nephritic and Hypertensive Individuals. — J. clin. Invest. 1940:*19:*89.

MÖLLER, E., MCINTOSH, J.F., and VAN SLYKE, D. D.: Studies of Urea Excretion. — J. clin. Invest. 1929:*6:*427.

MOLNAR, G. W., TOWBIN, E. J., GOSSELIN, R. E., BROWN, A. H., and ADOLPH, E. F.: A Comparative Study of Water, Salt and Heat Exchanges of Men in Tropical and Desert Environments. — Amer. J. Hyg. 1946:*44:*411.

MOREIRA, M., JOHNSON, R. E., FORBES, A. P., and CONSOLAZIO, F. C.: Adrenal Cortex and Work in Heat. — Amer. J. Physiol. 1945:*143:*169.

MUDGE, G. H., FOULKS, J., and GILMAN, A.: The Renal Excretion of Potassium. — Proc. Soc. exp. Biol. (N.Y.) 1948:*67:*545.

MUDGE, G. H., FOULKS, J., and GILMAN, A.: Renal Secretion of Potassium in the Dog during Cellular Dehydration. — Amer. J. Physiol. 1950:*161:* 159.

MURPHY, R. J. F., and STEAD, E. A., JR.: Effect ofExogenous and Endogenous Posterior Pituitary Antidiuretic Hormone on Water and Electrolyte Excretion. — J. clin. Invest. 1951:*30:*1055.

NEWBURGH, L. H., and JOHNSTON, M. W.: The Insensible Loss of Water. — Physiol. Rev. 1942:*22:*1.

NOETHER, G. E.: Use of the Range Instead of the Standard Deviation. — J. Amer. stat. Ass. 1955:*50:*1040.

NORN, M.: Untersuchungen über das Verhalten des Kaliums im Organismus; über Schwankungen der Kalium-, Natrium- und Chloridausscheidung durch die Niere im Verlaufe des Tages. — Skand. Arch. Physiol. 1929:*55:*184.

OTT, V. R.: Die Sauna. — Benno Schwabe & Co., Basel, 1948.

PEKKARINEN, A., and KINNUNEN, O.: On the Physiological Effects of the Finnish Steam-bath: The Excretion of 17-Ketosteroids and the Reactions of Eosinophils. — Acta endocr. (Kbh.) 1951:*7:*282.

PFEIFFER, J. B., Jr., and WOLFF, H. G.: Studies in Renal Circulation during Periods of Life Stress and Accompanying Emotional Reactions in Subjects with and without Essential Hypertension. — J. clin. Invest. 1950:*29:*1227.

PINSON, E. A.: Evaporation from Human Skin with Sweat Glands Inactivated. — Amer. J. Physiol. 1942:*137:*492.

PITTS, G. C., JOHNSON, R. E., and CONSOLAZIO, F. C.: Work in the Heat as Affected by Intake of Water, Salt and Glucose. — Amer. J. Physiol. 1944:*42:*253.

PITTS, R. F., and ALEXANDER, R. S.: The Renal Reabsorptive Mechanism for Inorganic Phosphate in Normal and Acidotic Dogs. — Amer. J. Physiol. 1944:*142:*648.

PRUNTY, F. T. G., MCSWINEY, R. R., MILLS, I. H., and SMITH, M. A.: The Effects of Aldosterone in Addison's Disease and Adrenal Pseudohermaphroditism. — Lancet 1954:*II*:620.

RADIGAN, L. R., and ROBINSON, S.: Effects of Environmental Heat Stress and Exercise on Renal Blood Flow and Filtration Rate. — J. appl. Physiol. 1949:*2*:185.

RÄSÄNEN, M. A.: Kliinisiä tutkimuksia suomalaisten sydäninfarktipotilaiden elinajasta ja siihen vaikuttavista tekijöistä, heidän työkyvystään infarktin jälkeen ja kestokyvystään suomalaisessa saunassa (Clinical Investigations of the Lifetime of Finnish Patients with Myocardial Infarction and Factors Influencing It, of their Capacity for Work after the Infarct and of their Power of Endurance in the Finnish Bath.) — Duodecim 1951:Suppl. 21.

REDISCH, W., WERTHEIMER, L., DELISIE, C., and STEELE, J. M.: Comparison of Various Vascular Beds in Man: Their Responses to a Simple Vasodilator Stimulus. — Circulation (N. Y.) 1954:*9*:63.

REUBI, F. C., and SCHROEDER, H. A.: Can Vascular Shunting Be Induced in the Kidney by Vasoactive Drugs? — J. clin. Invest. 1949:*28*:114.

RICHARDS, A. N., BOTT, P. A., and WESTFALL, B. B.: Experiments Concerning Possibility that Inulin Is Secreted by the Renal Tubules. — Amer. J. Physiol. 1938:*123*:281.

RICHARDS, A. N., WESTFALL, B. B., and BOTT, P. A.: Renal Excretion of Inulin, Creatinine and Xylose in Normal Dogs. — Proc. Soc. exp. Biol. (N.Y.) 1934:*32*:73.

RICHTER, A.: Die Wirkung der Thermalbäder auf die Nierentätigkeit. — Balneologe 1942:*9*:247.

ROBINSON, S., and ROBINSON, A. H.: Chemical Composition of Sweat. — Physiol. Rev. 1954:*34*:202.

ROBINSON, S., GERKING, S. D., TURREL, E. S., and KINCAID, R. K.: Effect of Skin Temperature on Salt Concentration of Sweat. — J. appl. Physiol. 1950:*2*:654.

ROBINSON, S., KINCAID, R. K., and RHAMY, R. K.: Effect of Desoxycorticosterone Acetate on Acclimatization of Men to Heat. — J. appl. Physiol. 1950:*2*:399. (a).

ROBINSON, S., KINCAID, R. K., and RHAMY, R. K.: Effect of Salt Deficiency on the Salt Concentration in Sweat. — J. appl. Physiol. 1950:*3*:55. (b).

ROBINSON, S., TURREL, E. S., and GERKING, S. D.: Physiologically Equivalent Conditions of Air Temperature and Humidity. — Amer. J. Physiol. 1945:*143*:21.

ROE, J. H.: A Colorimetric Method for the Determination of Fructose in Blood and Urine. — J. biol. Chem. 1934:*107*:15.

ROE, J. H., EPSTEIN, J. H., and GOLDSTEIN, N. P.: A Photometric Method for the Determination of Inulin in Plasma and Urine. — J. biol. Chem. 1949:*178*:839.

SALA, G., and LUETSCHER, J. A., JR.: The Effect of Sodium-retaining Corticoid, Electrocortin, Desoxycorticosterone, and Cortisone on Renal

Function and Excretion of Sodium and Water in Adrenalectomized Rats. — Endocrinology 1954:*55:*516.

Salassa, R. M., Mason, H. L., Mattox, V. R., Power, M. H., Orvis, A. L., and Sprague, R. G.: Effects of Aldosterone on Water, Electrolyte, and Nitrogen Balances in Addison's Disease. — J. Lab. clin. Med. 1955: *46:*946.

Selkurt, E. E.: Comparison of Renal Clearances with Direct Renal Blood Flow under Control Conditions and Following Renal Ischemia. — Amer. J. Physiol. 1946:*145:*376.

Selkurt, E. E.: Effect of Pulse Pressure and Mean Arterial Pressure Modification on Renal Hemodynamics and Electrolyte and Water Excretion. — Circulation (N. Y.) 1951:*4:*541.

Selkurt, E. E., Hall, P. W., and Spencer, P.: Influence of Graded Arterial Pressure Decrement on Renal Clearance of Creatinine, p-Aminohippurate and Sodium. — Amer. J. Physiol. 1949:*159:*369.

Shannon, J. A., and Smith, H. W.: The Excretion of Inulin, Xylose and Urea by Normal and Phlorizinized Man. — J. clin. Invest. 1935:*14:*393.

Sheppard, R. H., Morse, W. I., Renold, A. E., and Thorn, G. W.: Studies on Aldosterone in Man. — J. clin. Endocr. 1955:*15:*853.

Shipley, R. E., and Study, R. S.: Changes in Renal Blood Flow, Extraction of Inulin, Glomerular Filtration Rate, Tissue Pressure and Urine Flow with Acute Alterations of Renal Artery Blood Pressure. — Amer. J. Physiol. 1951:*167:*676.

Simpson, S. A., Tait, J. F., Wettstein, A., Neher, R., Euw, J. von, and Reichstein, T.: Isolierung eines neuen kristallisierten Hormons aus Nebennieren mit besonders hoher Wirksamkeit auf den Mineralstoffwechsel. — Experientia (Basel) 1953:*9:*333.

Simpson, S. A., Tait, J. F., Wettstein, A., Neher, R., Euw, J. von, Schindler, O., and Reichstein, T.: Konstitution des Aldosterons, des neuen Mineralocorticoids. — Experientia (Basel) 1954:*10:*132.

Sirota, J. H., Baldwin, D. S., and Villarreal, H.: Diurnal Variations of Renal Function in Man. — J. clin. Invest. 1950:*29:*187.

Sirota, J. H., and Kroop, I. G.: Evidence Suggesting Renal Tubular Excretion of Potassium in Man during Recovery from Acute Renal Insufficiency. — J. clin. Invest. 1951:*30:*1082.

Smit, J., Alkemade, C. T. J., and Vershure, J. C. M.: A Contribution to the Development of the Flame-photometric Determination of Sodium and Potassium in Blood Serum. — Biochim. et biophys. Acta 1951: *6:*508.

Smith, F. E.: Indices of Heat Stress. — Med. Res. Council Memo. No. 29, H. M. Stationery Office, London, 1955.

Smith, H. W.: The Kidney, Structure and Function in Health and Disease. — Oxford University Press, New York 1951.

Smith, H. W., Finkelstein, N., Aliminosa, L., Crawford, B., and Graber, M.: The Renal Clearances of Substituted Hippuric Acid Derivatives and Other Aromatic Acids in Dog and Man. — J. clin. Invest. 1945:*24:*388.

SMITH, H. W., GOLDRING, W., and CHASIS, H.: The Measurement of the Tubular Excretory Mass, Effective Blood Flow and Filtration Rate in the Normal Human Kidney. — J. clin. Invest. 1938:*17:*263.

SMITH, J. H., ROBINSON, S., and PEARCY, M.: Renal Responses to Exercise, Heat and Dehydration. — J. appl. Physiol. 1952:*4:*659.

SOMOGYI, M.: A Method for the Preparation of Biood Filtrates for the Determination of Sugar. — J. biol. Chem. 1930:*86:*655.

STANBURY, S. W., and THOMSON, A. E.: Diurnal Variations in Electrolyte Excretion. — Clin. Sci. 1951:*10:*267.

STEINITZ, K.: A Colorimetric Method for the Determination of Inulin in Blood Plasma and Urine. — J. biol. Chem. 1938:*126:*589.

STREETEN, D. H. P., CONN, J. W., LOUIS, L. H., FAJANS, S. S., SELTZER, H. S., JOHNSON, R. D., GITTER, R. D., and DUBE, A. H.: Secondary Aldosteronism, I: The Metabolic and Adrenocortical Responses of Normal Men to High Environmental Temperatures. — J. Lab. clin. Med. 1955:*46:*957.

SYDNOR, K. L., SWEAT, M. L., SAYERS, G., and HALE, H. B.: Blood ACTH and Corticosteroids in Man Exposed to Environmental Stress. — U.S. Air Force, School of Aviation Medicine, Rep. No. 55—22, 1955.

TALBOT, J. H.: Heat Cramps. — Medicine (Baltimore) 1935:*14:*323.

TALBOT, J. H., EDWARDS, H. T., DILL, D. B., and DRASTICH, L.: Physiological Responses to High Environmental Temperature. — Amer. J. trop. Med. 1933:*13:*381.

TAYLOR, H. L., HENSCHEL, A., MICKELSEN, O., and KEYS, A.: The Effect of the Sodium Chloride Intake on the Work Performance of Man during Exposure to Dry Heat and Experimental Heat Exhaustion. — Amer. J. Physiol. 1943:*140:*439.

THORN, G. W., RENOLD, A. E., MORSE, W. I., GOLDFIEN, A., and REDDY, W. J.: Highly Potent Adrenal Cortical Steroids: Structure and Biologic Activity. — Ann. intern. Med. 1955:*43:*979. (a).

THORN, G. W., SHEPPARD, R. H., MORSE, W. I., REDDY, W. J., BEIGELMAN, P. M., and RENOLD, A. E.: Comparative Action of Aldosterone and 9-Alpha-fluorohydrocortisone in Man. — Ann. N. Y. Acad. Sci. 1955: *61:*609. (b).

VAN HEYNINGEN, see under H.

VENNING, E. H., DYRENFURTH, I., and GIROUD, C.: Diurnal Variation in Excretion of a Sodium-retaining Substance. — Fed. Proc. 1955:*14:*297.

VIHERJUURI, H. J.: Sauna, the Finnish Bath. — Otava, Helsinki, 1954.

VIVARIO, R., VAN BENEDEN, J., VAN CAUWENBERGE, H., and HEUSGHEM, C.: Cures thermales et stimulation corticosurrénalienne. — Rev. méd. Liège 1952:*7:*83.

WARREN, J. W.: Observations on Renal Venous Blood in Normal Unanesthetized Subjects and Patients with Severe Congestive Heart Failure. — J. clin. Invest. 1944:*23:*928.

WEINER, J. S.: The Regional Distribution of Sweating. — J. Physiol. (Lond.) 1945:*104:*32.

Weiner, J. S.: Renal Function of Men Working in Hot Environments. — — Proc. 17th intern. physiol. Congress 1947:p. 124.

Weiner, J. S., and van Heyningen, R. E.: Salt Losses of Men Working in Hot Environments. — Brit. J. industr. Med. 1952:*9:*56. (a).

Weiner, J. S., and van Heyningen, R. E.: Relation of Skin Temperature to Salt Concentration of General Body Sweat. — J. appl. Physiol. 1952: *4:*725. (b).

Werkö, L., Bucht, H., and Josephson, B.: The Renal Extraction of Para-amino-hippuric Acid and Oxygen in Man during Postural Changes of the Circulation. — Scand. J. clin. Invest. 1949:*1:*321.

White, A. G., Rubin, G., and Leiter, L.: Studies in Edema, III: The Effect of Pitressin on the Renal Excretion of Water and Electrolytes in Patients with and without Liver Disease. — J. clin. Invest. 1951: *30:*1187.

Whitehouse, A. G. R.: Further Investigation of Sweating and Sweat. — Proc. roy. Soc. B. 1931:*108:*326.

Whitehouse, A. G. R.: The Dissolved Constituents of Human Sweat. — Proc. roy. Soc. B. 1935:*117:*139.

Wilke, H., and Voss, H. E.: Die Entfernung pyrogener Substanzen aus Injektionslösungen durch Filtration. — Arzneimittelforschung 1954: *4:*8.

Wolf, G. A.: The Effect of Pain on Renal Function. — Res. publ. Ass. nerv.ment. Dis. 1943:*23:*358.

Wyndham, C. H., van der Merwe Bouwer, W., Paterson, H. F., and Devine, M. G.: Examination of Heat Stress Indices. — Arch. industr. Hyg. 1953:*7:*221.

Yaglou, C. P.: Indices of Comfort. In Newburgh, L. H.: Physiology of Heat Regulation and the Science of Clothing. — W. B. Saunders & Co., Philadelphia, 1949.